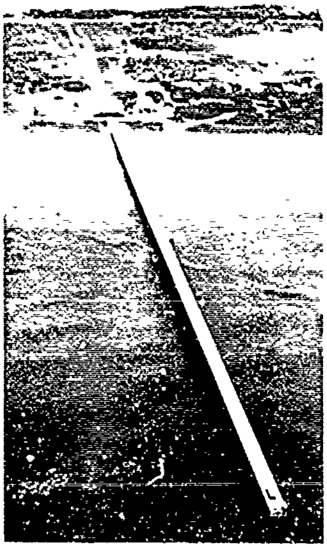
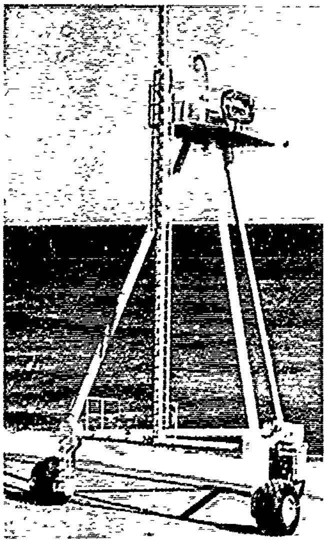
US Army Corps of Engineers





TECHNICAL REPORT CERC-91-9

ANNUAL DATA SUMMARY FOR 1989 CERC FIELD RESEARCH FACILITY

Volume I

MAIN TEXT AND APPENDIXES A AND B

by

Michael W. Leffler, Clifford F. Baron, Brian L. Scarborough
Kent K. Hathaway, Ralph T. Hayes

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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13. ABSTRACT (Maximum 200 words)

This report provides basic data and summaries for the measurements made during 1989 at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, NC. The report includes comparisons of the present year's data with cumulative statistics from 1980 to the present.

Summarized in this report are meteorological and oceanographic data, monthly bathymetric survey results, samples of quarterly aerial photography, and descriptions of 17 storms that occurred during the year. The year was highlighted by a severe storm in March that destroyed or damaged over 100 ocean front structures. Waves with 4-m significant height were measured 6 km from shore.

This report is eleventh in a series of annual summaries of data collected at the FRF that began with Miscellaneous Report CERC-82-16, which summarizes data collected during 1977-1979. These reports are available from the WES Technical Report Distribution Section of the Information Technology Laboratory, Vicksburg, MS.

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PREFACE

This report is the eleventh in a series of annual data summaries authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32525, Field Research Facility Analysis, Coastal Flooding Program. Funds were provided through the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), under the program management of Dr. C. Linwood Vincent, CERC. Mr. John H. Lockhart, Jr., was HQUSACE Technical Monitor.

The data for the report were collected and analyzed at the WES/CERC Field Research Facility (FRF) in Duck, NC. The report was prepared by Mr. Michael W. Leffler, Computer Programmer Analyst, FRF, under the direct supervision of Mr. William A. Birkemeier, Chief, FRF Group, Engineering Development Division (EDD), and Mr. Thomas W. Richardson, Chief, EDD; and under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively. Messrs. Kent K. Hathaway, Oceanographer, FRF, and Ralph T. Hayes, Electronics Technician, FRF, assisted with instrumentation; and Mr. Brian L. Scarborough, Amphibious Vehicle Operator, FRF, assisted with data collection. Messrs. Clifford F. Baron, James E. Martin, and Mark A. McConathy, and Ms. Wendy L. Smith assisted with data analysis at the FRF. The National Oceanic and Atmospheric Administration/National Ocean Service maintained the tide gage and provided statistics for summarization.

Commander and Director of WES during the publication of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONTENTS (Continued)

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CONTENTS (Concluded)

ANNUAL DATA SUMMARY FOR 1989

CERC FIELD RESEARCH FACILITY

PART I: INTRODUCTION

Background

1. The US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF), located on 0.7 km^2 at Duck, NC (Figure 1), consists of a 561-m-long research pier and accompanying office and field support buildings. The FRF is located near the middle of Currituck Spit along a 100-km unbroken stretch of shoreline extending south of Rudee Inlet, VA, to Oregon Inlet, NC. The FRF is bordered by the Atlantic Ocean to the east and Currituck Sound to the west. The Facility is designed to (a) provide a rigid platform from which waves, currents, water levels, and bottom elevations can be measured, especially during severe storms; (b) provide CERC with field experience and data to complement laboratory and analytical studies and numerical models; (c) provide a manned field facility for testing new instrumentation; and (d) serve as a permanent field base of operations for physical and biological studies of the site and adjacent region.

2. The research pier is a reinforced concrete structure supported on 0.9-m-diam steel piles spaced 12.2 m apart along the pier's length and 4.6 m apart across the width. The piles are embedded approximately 20 m below the ocean bottom. The pier deck is 6.1 m wide and extends from behind the duneline to about the 6-m water depth contour at a height of 7.8 m above the National Geodetic Vertical Datum (NGVD). The pilings are protected against sand abrasion by concrete erosion collars and against corrosion by a cathodic system.

3. An FRF Measurements and Analysis Program has been established to collect basic oceanographic and meteorological data at the site, reduce and analyze these data, and publish the results.

4. This report, which summarizes data for 1989, continues a series of reports begun in 1977.

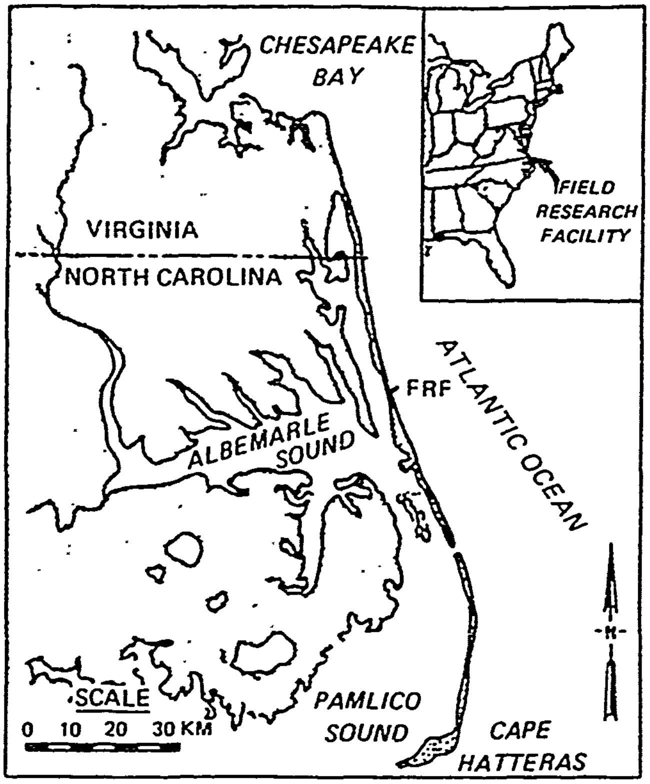

Figure 1. FRF location map

Organization of Report

5. This report is organized into nine parts and five appendixes. Part I is an introduction; Parts II through VIII discuss the various data collected during the year; and Part IX describes the storms that occurred. Appendix A presents the bathymetric surveys, Appendix B summarizes deepwater wave statistics, and Appendixes C through E (published under separate cover as Volume II) contain summary statistics for other gages.

6. In each part of this report, the respective instruments used for monitoring the meteorological or oceanographic conditions are briefly described along with data collection and analysis procedures and data results. The instruments were interfaced with the primary data acquisition system, a Digital Equipment Corporation (Maynard, MA) VAX-11/750 minicomputer located in the FRF laboratory building. More detailed explanations of the design and the operation of the instruments may be found in Miller (1980). Readers' comments on the format and usefulness of the data presented are encouraged.

Availability of Data

7. Table 1 summarizes the available data. In addition to the wave data summaries in the main text, more extensive summaries for each of the wave gages are provided in Appendixes B through E.

Table 1

1989 Data Availability

	Gage ID	Jan					Feb				Mar				Apr					May				Jun				Jul					Aug				Sep				Oct					Nov				Dec			
		1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4
Weather																																																					
Anemometer	932	*	*	*	*	*	/	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	/	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*
Atmospheric Pres.	616	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*
Air Temperature	624	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	/	-	/	*	*	*	*	*	*	*	*	*	*	/	*
Precipitation	604	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Waves																																																					
Offshore Waverider	630	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	*	*	*	*	*	/	*	*	*	*	/	/	!	/	*	*	*	*	*	/	/	-	/	*
Pressure Gage	111	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	*	*	*	*	*	*	*	/	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*
Pier End	625	-	-	-	-	-	-	-	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	/
Pier Nearshore	645	/	*	*	*	*	/	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	/	/	/	*	*	-	-	-	-	/	/	/
Currents																																																					
Pier End		*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/
Pier Nearshore		*	*	*	*	*	*	*	*	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/
Beach		*	*	*	*	*	*	*	*	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	/	*	*	/	*	*	*	*	*	/
Pier End Tide Gage		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	*	/	*	*	*	*	*	/	*	*	*
Water Characteristics																																																					
Temperature		*	*	*	*	*	*	*	*	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/
Visibility		*	*	*	*	*	*	*	*	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/
Density		*	*	*	*	*	*	*	*	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	-	/	/
Bathymetric Surveys					*					*		*						*					*			*					*				*			*								*				*			
Photography																																																					
Beach		*	*	*	*	*	*	*	*	/	*	*	*	/	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	-	/	*	*	*	*	*	*	*	*	*	*	*	/
Aerial		*										*					*														*											*											

Notes: * Full week of data obtained.
/ Less than 7 days of data obtained.
- No data obtained.

8. The annual data summary herein summarizes daily observations by month and year to provide basic data for analysis by users. Daily measurements and observations have already been reported in a series of monthly Preliminary Data Summaries (FRF 1989). If individual data for the present year are needed, the user can obtain detailed information (as well as the monthly and previous annual reports) from the following address:

USAE Waterways Experiment Station
Coastal Engineering Research Center
Field Research Facility
1261 Duck Road
Kitty Hawk, NC 27949-9440

Although the data collected at the FRF are designed primarily to support ongoing CERC research, use of the data by others is encouraged. The WES/CERC Coastal Engineering Information and Analysis Center (CEIAC) is responsible for storing and disseminating most of the data collected at the FRF. All data requests should be in writing and addressed to:

Commander and Director
US Army Engineer Waterways Experiment Station
ATTN: Coastal Engineering Information Analysis Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Tidal data other than the summaries in this report can be obtained directly from the following address:

National Oceanic and Atmospheric Administration
National Ocean Service
ATTN: Tide Analysis Branch
Rockville, MD 20852

A complete explanation of the exact data desired for specific dates and times will expedite filling any request; an explanation of how the data will be used will help CEIAC or the National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) determine if other relevant data are available. For information regarding the availability of data for all years, contact CEIAC at (601) 634-2012. Costs for collecting, copying, and mailing will be borne by the requester.

PART II: METEOROLOGY

9. This section summarizes the meteorological measurements made during the current year and in combination with all previous years. Meteorological measurements during storms are given in Part IX.

10. Mean air temperature, atmospheric pressure, and wind speed and direction were computed for each data file, which consisted of data sampled two times per second for 34 min every 6 hr beginning at or about 0100, 0700, 1300, and 1900 eastern standard time (EST); these hours correspond to the time that the National Weather Service (NWS) creates daily synoptic weather maps. During storms, data recordings were made more frequently. The data are summarized in Table 2.

Table 2

Meteorological Statistics

	Mean Air Temperature deg C		Mean Atmospheric Pres. mb		Precipitation, mm				Wind Resultants			
					1989	1978-1989			1989		1980-1989	
Month	1989	1983-1989	1989	1983-1989	Total	Mean	Maxima	Minima	Speed m/sec	Direction deg	Speed m/sec	Direction deg
Jan	8.1	5.4	1019.3	1017.9	59	96	180	44	2.1	316	2.6	337
Feb	7.0	6.1	1019.5	1017.4	113	76	113	20	3.5	352	2.0	350
Mar	10.0	9.3	1017.5	1016.3	206	92	206	35	3.0	16	1.6	1
Apr	13.4	13.5	1014.5	1013.4	104	96	182	0	0.3	53	0.3	324
May	18.5	18.7	1013.2	1016.0	97	67	239	20	1.5	212	0.5	186
Jun	25.0	23.5	1014.1	1015.4	117	84	130	27	2.8	196	1.2	198
Jul	25.9	26.0	1015.1	1016.4	275	100	275	19	1.4	183	1.7	212
Aug	25.6	25.9	1013.3	1016.3	63	101	221	30	0.9	75	0.5	94
Sep	24.6	22.4	1015.9	1017.8	226	88	226	5	3.7	65	2.0	40
Oct	17.7	17.4	1016.7	1019.6	63	64	143	17	1.8	10	2.4	26
Nov	13.1	13.3	1014.8	1018.3	92	93	145	26	1.5	294	1.8	353
Dec	2.9	7.4	1015.7	1019.5	113	66	131	4	4.1	338	2.3	333
Average	16.0	15.7	1015.8	1017.1	127	85			0.9	356	0.9	357
Total					1528	1023						

Air Temperature

11. The FRF enjoys a typical marine climate that moderates the temperature extremes of both summer and winter.

Measurement instruments

12. A Yellow Springs Instrument Company, Inc. (YSI) (Yellow Springs, OH), electronic temperature probe with analog output interfaced to the FRF's computer was operated beside the NWS's meteorological instrument shelter located 43 m behind the dune (Figure 2). To ensure proper temperature

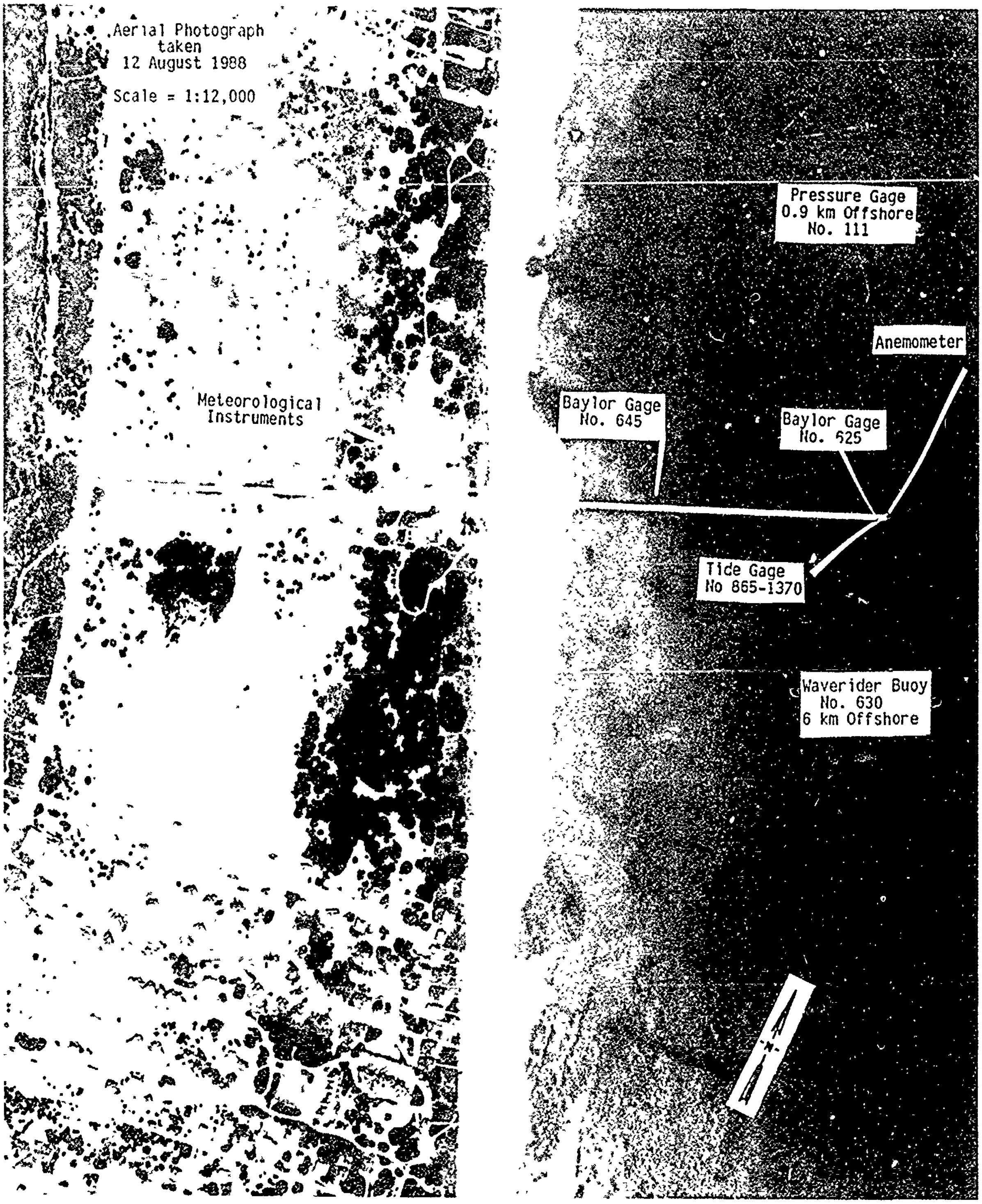

Figure 2. FRF gage locations

readings, the probe was installed 3 m aboveground inside a "coolie hat" to shade it from direct sun, yet provide proper ventilation.

Results

13. Daily and average air temperature values are tabulated in Table 2 and shown in Figure 3.

Atmospheric Pressure

Measurement instruments

14. Electronic atmospheric pressure sensor. Atmospheric pressure was measured with a YSI electronic sensor with analog output located in the laboratory building at 9 m above NGVD. Data were recorded on the FRF computer. Data from this gage were compared with those from an NWS aneroid barometer to ensure proper operation.

15. Microbarograph. A Weathertronics, Incorporated (Sacramento, CA), recording aneroid sensor (microbarograph) located in the laboratory building also was used to continuously record atmospheric pressure variation.

16. The microbarograph was compared daily with the NWS aneroid barometer, and adjustments were made as necessary. Maintenance of the microbarograph consisted of inking the pen, changing the chart paper, and winding the clock every 7 days. During the summer, a meteorologist from the NWS checked and verified the operation of the barometer.

17. The microbarograph was read and inspected daily using the following procedure:

a. The pen was zeroed (where applicable).

b. The chart time was checked and corrected, if necessary.

c. Daily reading was marked on the chart for reference.

d. The starting and ending chart times were recorded, as necessary.

e. New charts were installed when needed.

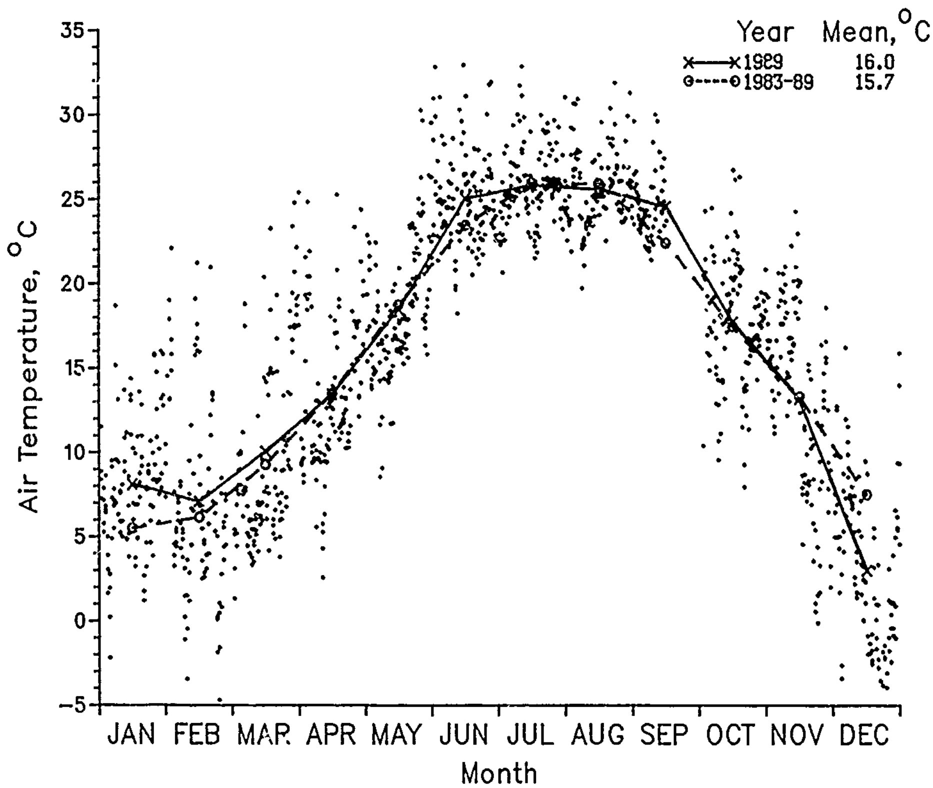

Figure 3. Daily air temperature values with monthly means

Results

18. Daily and average atmospheric pressure values are presented in Figure 4, and summary statistics are presented in Table 2.

Precipitation

19. Precipitation is generally well distributed throughout the year. Precipitation from midlatitude cyclones (northeasters) predominates in the winter, whereas local convection (thunderstorms) accounts for most of the summer rainfall.

Measurement instruments

20. Electronic rain gage. A Belfort Instrument Company (Baltimore, MD) 30-cm weighing rain gage, located near the instrument shelter 47 m behind the dune, measured daily precipitation. According to the manufacturer, the instrument's accuracy was 0.5 percent for precipitation amounts less than

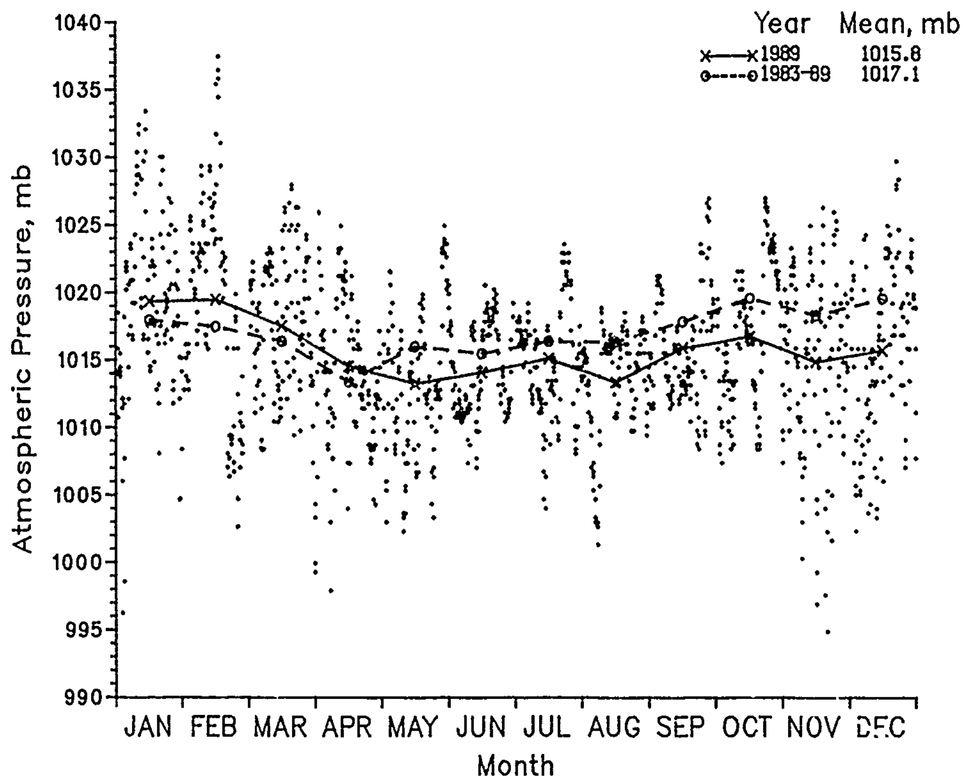

Figure 4. Daily barometric pressure values with monthly means

15 cm and 1.0 percent for amounts greater than 15 cm.

21. The rain gage was inspected daily, and the analog chart recorder was maintained by procedures similar to those for the microbarograph.

22. Plastic rain gage. An Edwards Manufacturing Company (Alberta Lea, MN) True Check 15-cm-capacity clear plastic rain gage with a 0.025-cm resolution was used to monitor the performance of the weighing rain gage. This gage, located near the weighing gage, was compared daily; and very few discrepancies were identified during the year.

Results

23. Daily and monthly average precipitation values are shown in Figure 5. Statistics of total precipitation for each month during this year and average totals for all years combined are presented in Table 2.

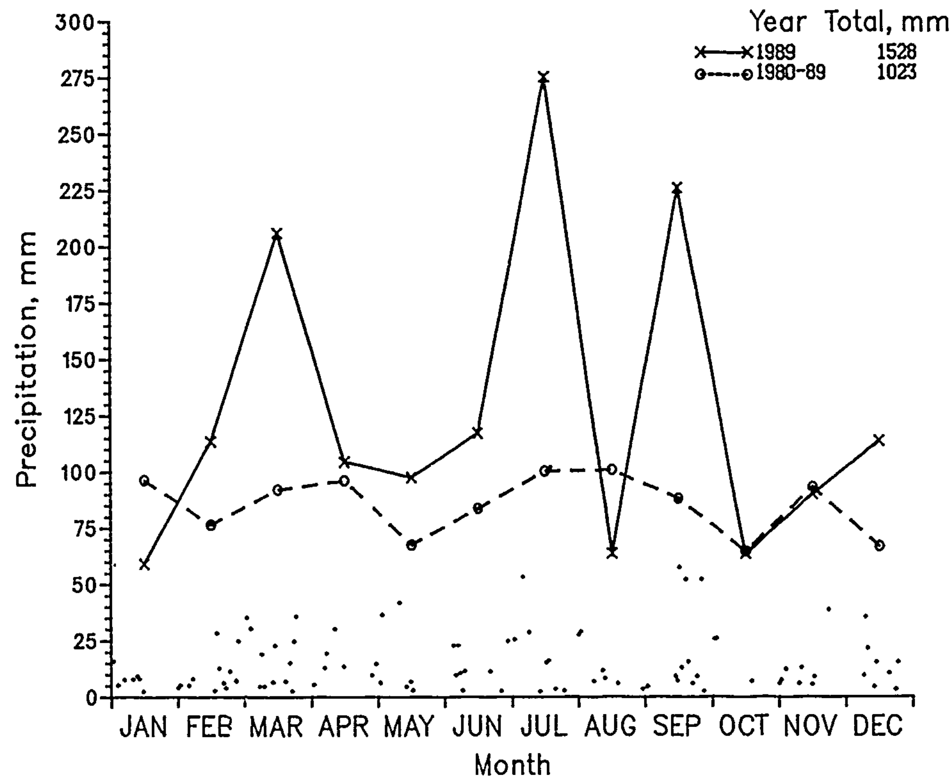

Figure 5. Daily precipitation values with monthly totals

Wind Speed and Direction

24. Winds at the FRF are dominated by tropical maritime air masses that create low to moderate, warm southern breezes; arctic and polar air masses that produce cold winds from northerly directions; and smaller scale cyclonic, low pressure systems, which originate either in the tropics (and move north along the coast) or on land (and move eastward offshore). The dominant wind direction changes with the season, being generally from northern directions in the fall and winter and from southern directions in the spring and summer. It is common for fall and winter storms (northeasters) to produce winds with average speeds in excess of 15 m/sec.

Measurement instrument

25. Winds were measured at the seaward end of the pier at an elevation of 19.1 m (Figure 2) using a Weather Measure Corporation (Sacramento, CA) Skyvane Model W102P anemometer. Wind speed and direction data were collected on the FRF computer. The anemometer manufacturer specifies an accuracy of $\pm$0.45 m/sec below 13 m/sec and 3 percent at speeds above 13 m/sec, with a

threshold of 0.9 m/sec. Wind direction accuracy is ± 2 deg with a resolution of less than 1 deg. The anemometer is calibrated annually at the National Bureau of Standards in Gaithersburg, MD, and is within the manufacturer's specifications.

Results

26. Annual and monthly joint probability distributions of wind speed versus direction were computed. Winds speeds were resolved into 3-m/sec intervals, whereas the directions were at 22.5-deg intervals (i.e. 16-point compass direction specifications). These distributions are presented as wind "roses," such that the length of the petal represents the frequency of occurrence of wind blowing from the specified direction, and the width of the petal is indicative of the speed. Resultant directions and speeds were also determined by vector averaging the data (see Table 2). Wind statistics are presented in Figures 6, 7, and 8.

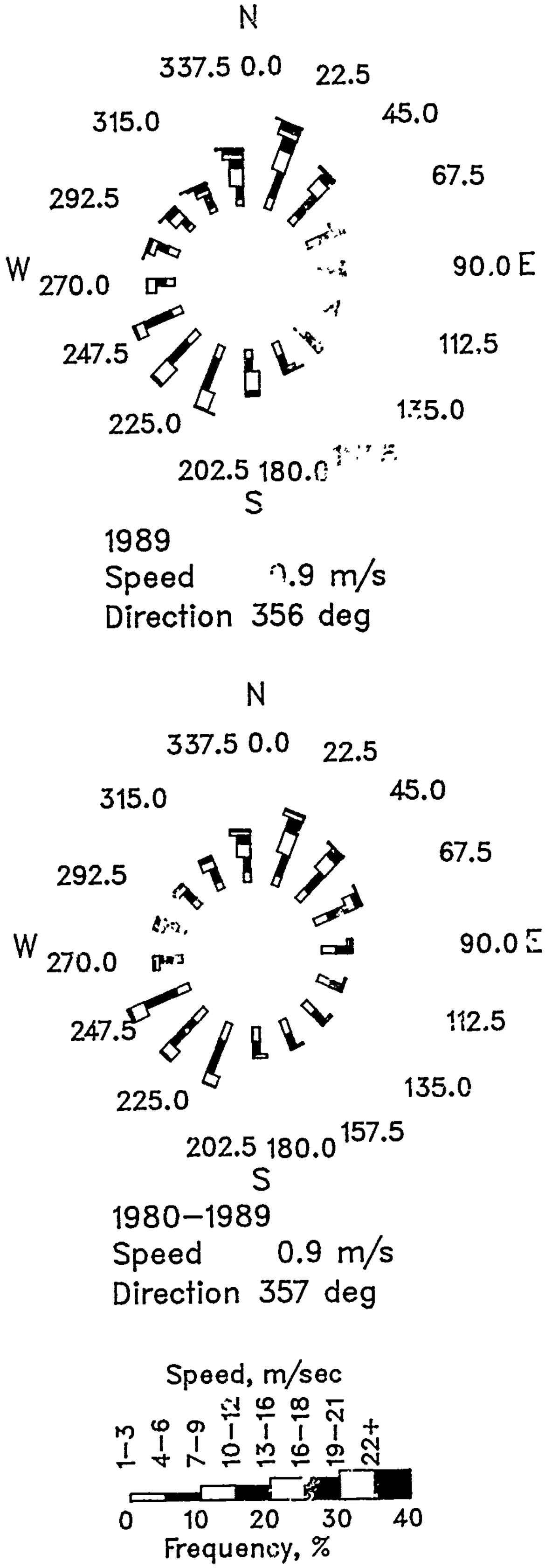

Figure 6. Annual wind roses

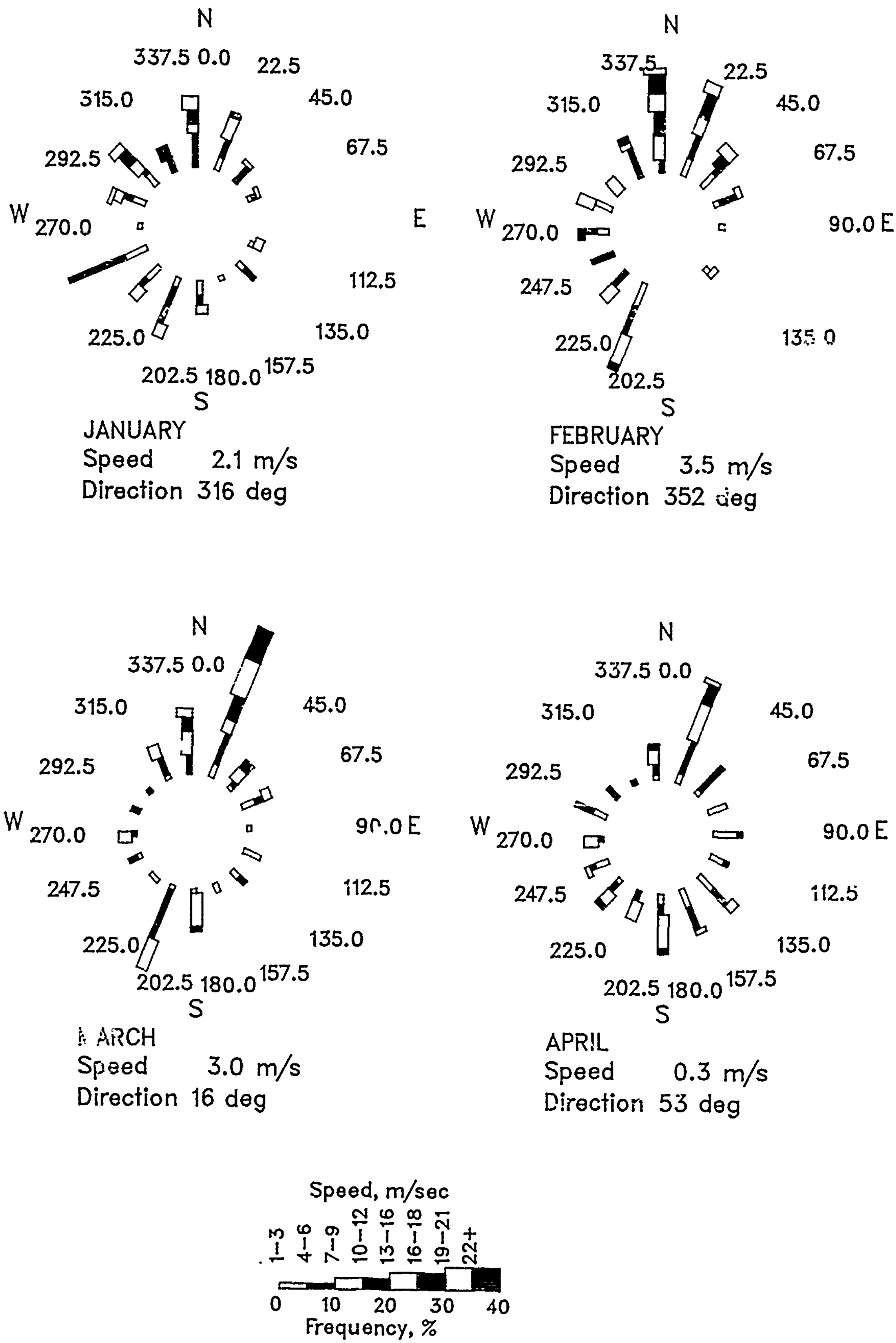

Figure 7. Monthly wind roses for 1989
(Sheet 1 of 3)

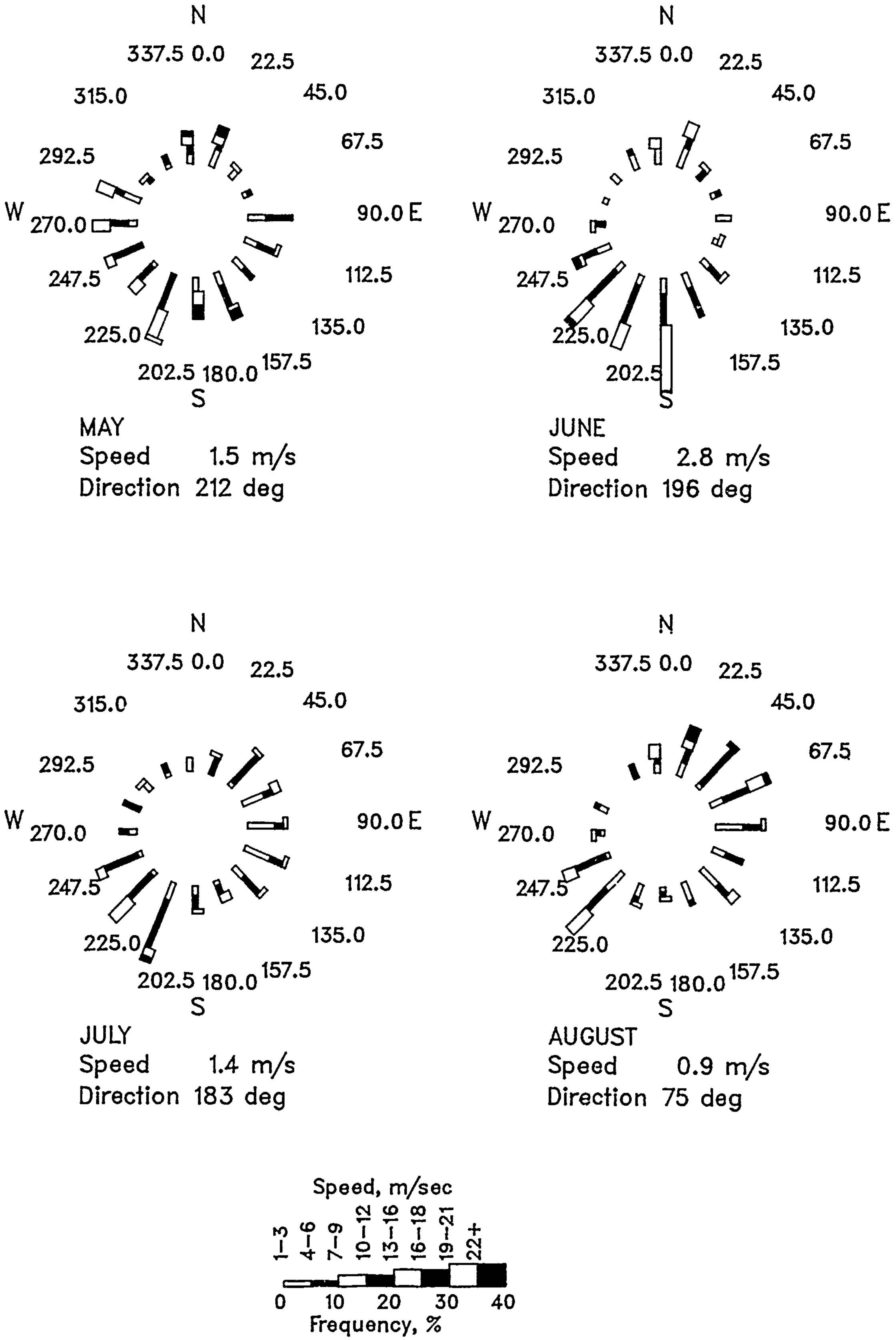

Figure 7. (Sheet 2 of 3)

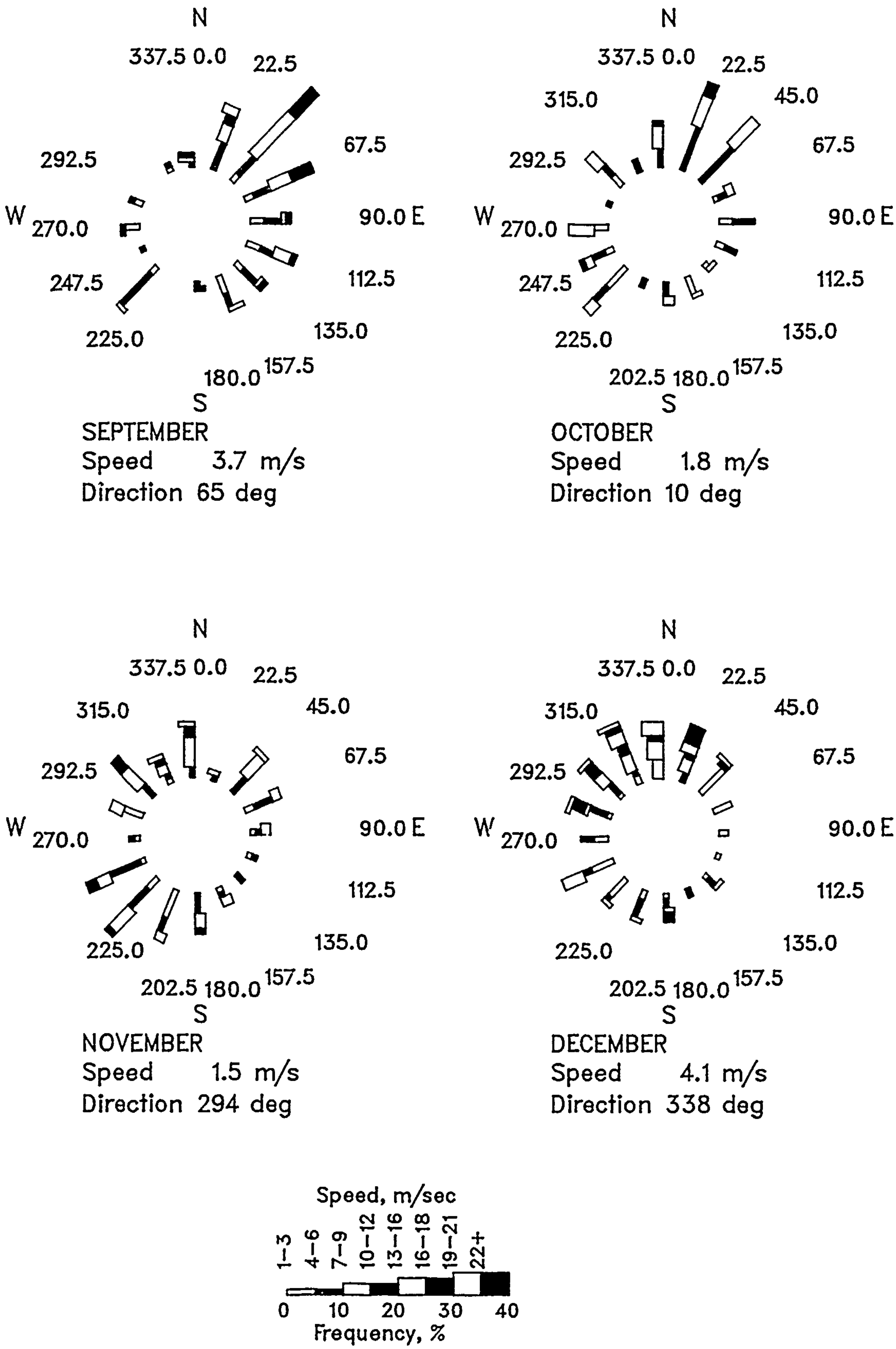

Figure 7. (Sheet 3 of 3)

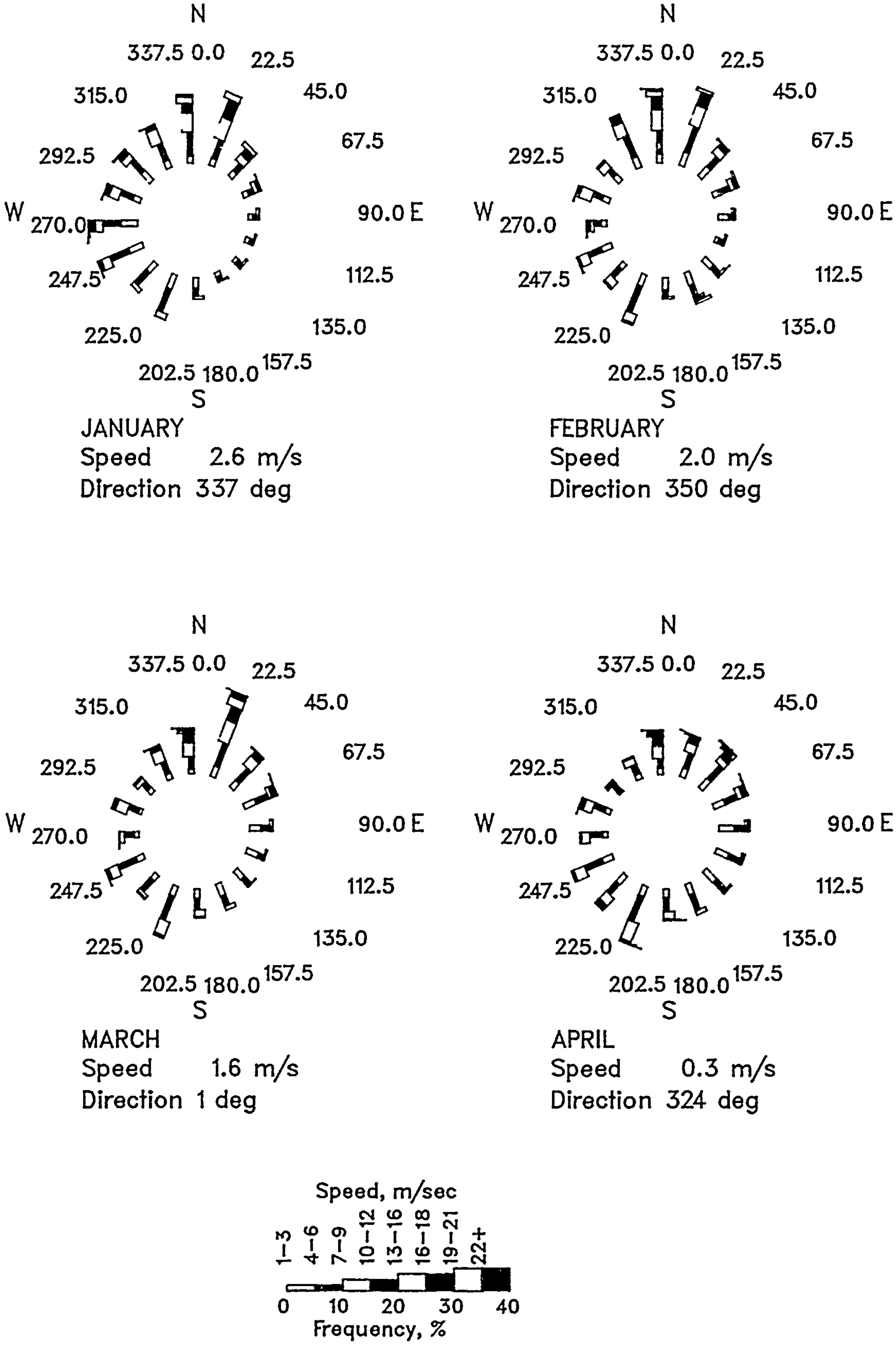

Figure 8. Monthly wind roses for 1980 through 1989 (Sheet 1 of 3)

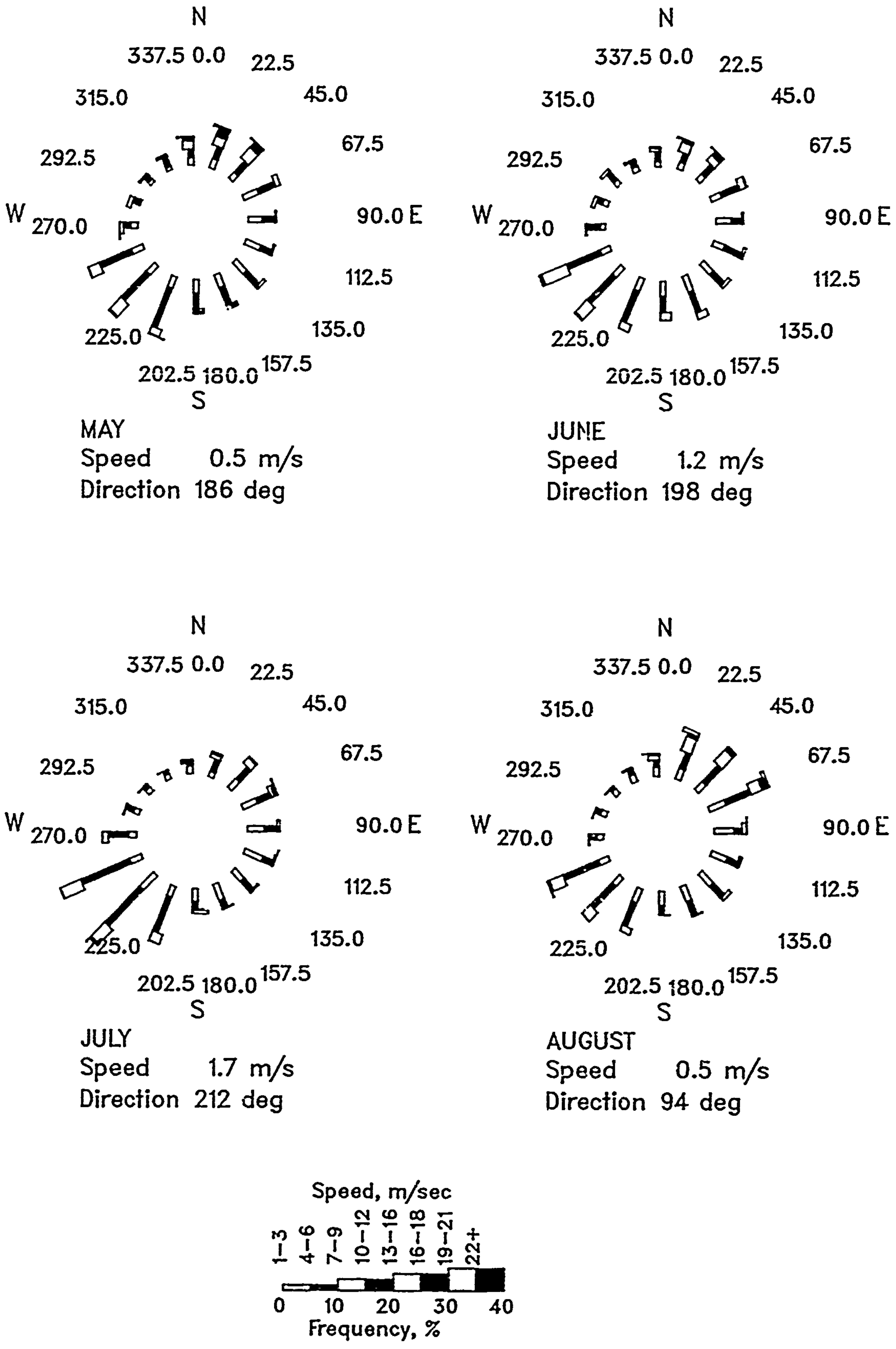

Figure 8. (Sheet 2 of 3)

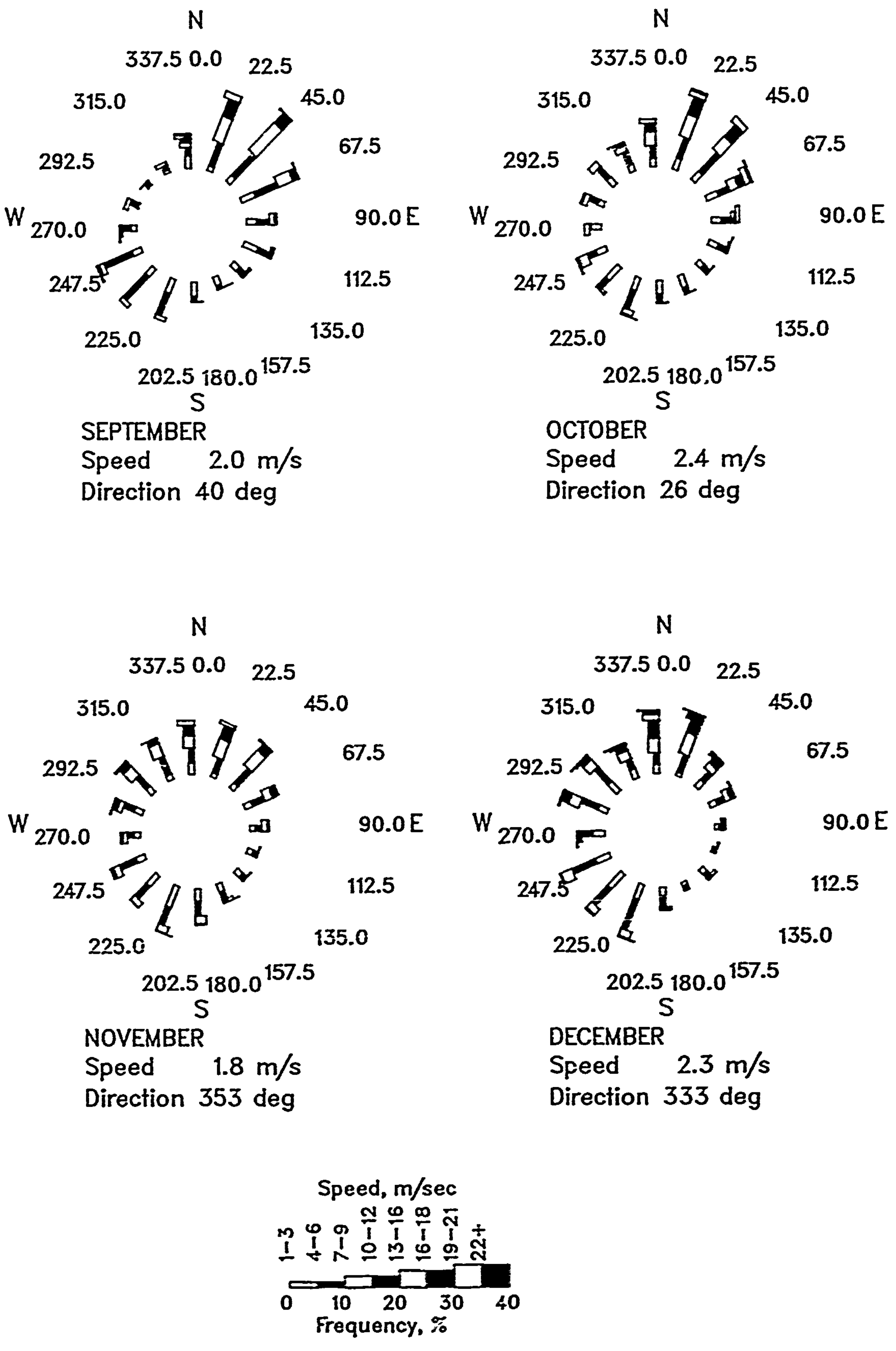

Figure 8. (Sheet 3 of 3)

PART III: WAVES

27. This section presents summaries of the wave data. A discussion of individual major storms is given in Part IX and contains additional wave data for times when wave heights exceeded 2 m at the seaward end of the FRF pier. Appendixes B through E provide more extensive data summaries for each gage, including height and period distributions, wave direction distributions, persistence tables, and spectra during storms.

28. Wave directions (similar to wind directions) at the FRF are seasonally distributed. Waves approach most frequently from north of the pier in the fall and winter and south of the pier in the summer, with the exception of storm waves that approach twice as frequently from north of the pier. Annually, waves are approximately evenly distributed between north and south (resultant wave direction being almost shore-normal).

Measurement Instruments

29. The wave gages included two wave staff (Gages 645 and 625), one buoy (Gage 630), and one pressure (Gage 111) gage as shown in Figure 2 and located as follows:

Gage Type/Number	Distance Offshore from Baseline	Water Depth m	Operational Period
Continuous wire (645)	238 m	3.5	11/84-12/89
Continuous wire (625)	579 m	8	11/78-12/89
Accelerometer buoy (630)	6 km	18	11/78-12/89
Pressure gage (111)	1 km	9	09/86-12/89

Staff gages

30. Two Baylor Company (Houston, TX) parallel cable inductance wave gages (Gage 645 at sta 7+80 and Gage 625 at sta 19+00 (Figure 2)) were mounted on the FRF pier. Rugged and reliable, these gages require little maintenance except to keep tension on the cables and to remove any material that may cause an electrical short between them. They were calibrated prior to installation by creating an electrical short between the two cables at known distances along the cable and recording the voltage output. Electronic signal conditioning amplifiers are used to ensure that the output signals from the gages are within a 0- to 5-V range. Manufacturer-stated gage accuracy is about 1.0 percent, with a 0.1-percent full-scale resolution; full scale is 14 m for Gage 625 and 8.2 m for Gage 645. These gages are susceptible to

lightning damage, but protective measures have been taken to minimize such occurrences. A more complete description of the gages' operational characteristics was given by Grogg (86).

Buoy gage

31. One Datawell Laboratory for Instrumentation (Haarlem, The Netherlands) Waverider buoy gage (Gage 630) measures the vertical acceleration produced by the passage of a wave. The acceleration signal is double-integrated to produce a displacement signal transmitted by radio to an onshore receiver. The manufacturer stated that wave amplitudes are correct to within 3 percent of their actual value for wave frequencies between 0.065 and 0.500 Hz (corresponding 15- to 2-sec wave periods). The manufacturer also specified that the error gradually increased to 10 percent for wave periods in excess of 20 sec. The results in this report were not corrected for the manufacturer's specified amplitude errors. However, the buoy was calibrated semiannually to ensure that it was within the manufacturer's specification.

Pressure gage

32. One Senso-Metrics, Incorporated (Simi Valley, CA), pressure transduction gage (Gage 111) installed near the ocean bottom measures the pressure changes produced by the passage of waves creating an output signal that is linear and proportional to pressure when operated within its design limits. Predeployment and postdeployment precision calibrations are performed at the FRF using a static deadweight tester. The sensor's range is 0 to 25 psi (equivalent to 0- to 17-m seawater) above atmospheric pressure with a manufacturer-stated accuracy of ± 0.25 percent. Copper scouring pads are installed at the sensor's diaphragm to reduce biological fouling, and the system is periodically cleaned by divers.

Digital Data Analysis and Summarization

33. The data were collected, analyzed, and stored on magnetic tape using the FRF's VAX computer. Data sets were normally collected every 6 hr. During storms, the collection was at 3-hr intervals. For each gage, a data set consisted of four contiguous records of 4,096 points recorded at 0.5 Hz (approximately 34-min long), for a total of 2 hr and 16 min. Analysis was performed on individual 34-min records.

34. The analysis program computes the first moment (mean) and the

second moment about the mean (variance) and then edits the data by checking for "jumps," "spikes," and points exceeding the voltage limit of the gage. A jump is defined as a data value greater than five standard deviations from the previous data value, whereas a spike is a data value more than five standard deviations from the mean. If less than five consecutive jumps or spikes are found, the program linearly interpolates between acceptable data and replaces the erroneous data values. The editing stops if the program finds more than five consecutive jumps or spikes or more than a total of 100 bad points or the variance of the voltage is below 1×10^{-5} squared volts. The statistics and diagnostics from the analysis are saved.

35. Sea surface energy spectra are computed from the edited time series. Spectral estimates are computed from smaller data segments obtained by dividing the 4,096-point record into several 512-point segments. The estimates are then ensemble-averaged to produce a more accurate spectrum. These data segments are overlapped by 50 percent (known as the Welch (1967) method) and have been shown to produce improved statistical properties than from nonoverlapped segments. The mean and linear trends are removed from each segment prior to spectral analysis. To reduce sidelobe leakage in the spectral estimates, a data window was applied. The first and last 10 percent of data points was multiplied by a cosine bell (Bingham, Godfrey, and Tukey 1967). Spectra were computed from each segment with a discreet Fast Fourier Transform and then ensemble-averaged. Sea surface spectra from subsurface pressure gages were obtained by applying the linear wave theory transfer function.

36. Unless otherwise stated, wave height in this report refers to the energy-based parameter H_{mo} defined as four times the zeroth moment wave height of the estimated sea surface spectrum (i.e., four times the square root of the variance) computed from the spectrum passband. Energy computations from the spectra are limited to a passband between 0.05 and 0.50 Hz for surface gages and between 0.05 Hz and a high frequency cutoff for subsurface gages. This high frequency limit is imposed to eliminate aliased energy and noise measurements from biasing the computation of H_{mo} and is defined as the frequency where the linear theory transfer function is less than 0.1 (spectral values are multiplied by 100 or more). Smoother and more statistically significant spectral estimates are obtained by band-averaging contiguous spectral components (three components are averaged per band producing a

frequency band width of 0.0117 Hz).

37. Wave period T_p is defined as the period associated with the maximum energy band in the spectrum, which is computed using a 3-point running average band on the spectrum. The peak period is reported as the reciprocal of the center frequency (i.e., T_p = 1/frequency) of the spectral band with the highest energy. A detailed description of the analysis techniques are presented in a report by Andrews (1987).*

Results

38. The wave conditions for the year are shown in Figure 9. For all four gages, the distributions of wave height for the current year and all years combined are presented in Figures 10 and 11, respectively. Distributions of wave period are presented in Figure 12.

39. Multiple year comparisons of data for Gage 111 actually incorporate data for 1985 and 1986 from Gage 640, a discontinued Waverider buoy previously located at the approximate depth and distance offshore as Gage 111 and data for 1987 from Gage 141, located 30 m south of Gage 111.

40. Refraction, bottom friction, and wave breaking contribute to the observed differences in height and period. During the most severe storms when the wave heights exceed 3 m at the seaward end of the pier, the surf zone (wave breaking) has been observed to extend past the end of the pier and occasionally 1 km offshore. This occurrence is a major reason for the differences in the distributions between Gage 630 and the inshore gages. The wave height statistics for the staff gage (Gage 645), located at the landward end of the pier, were considerably lower than those for the other gages. In all but the calmest conditions, this gage is within the breaker zone. Consequently, these statistics represent a lower energy wave climate.

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* M. E. Andrews. 1987. "Standard Wave Data Analysis Procedures for Coastal Engineering Applications," unpublished report prepared for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

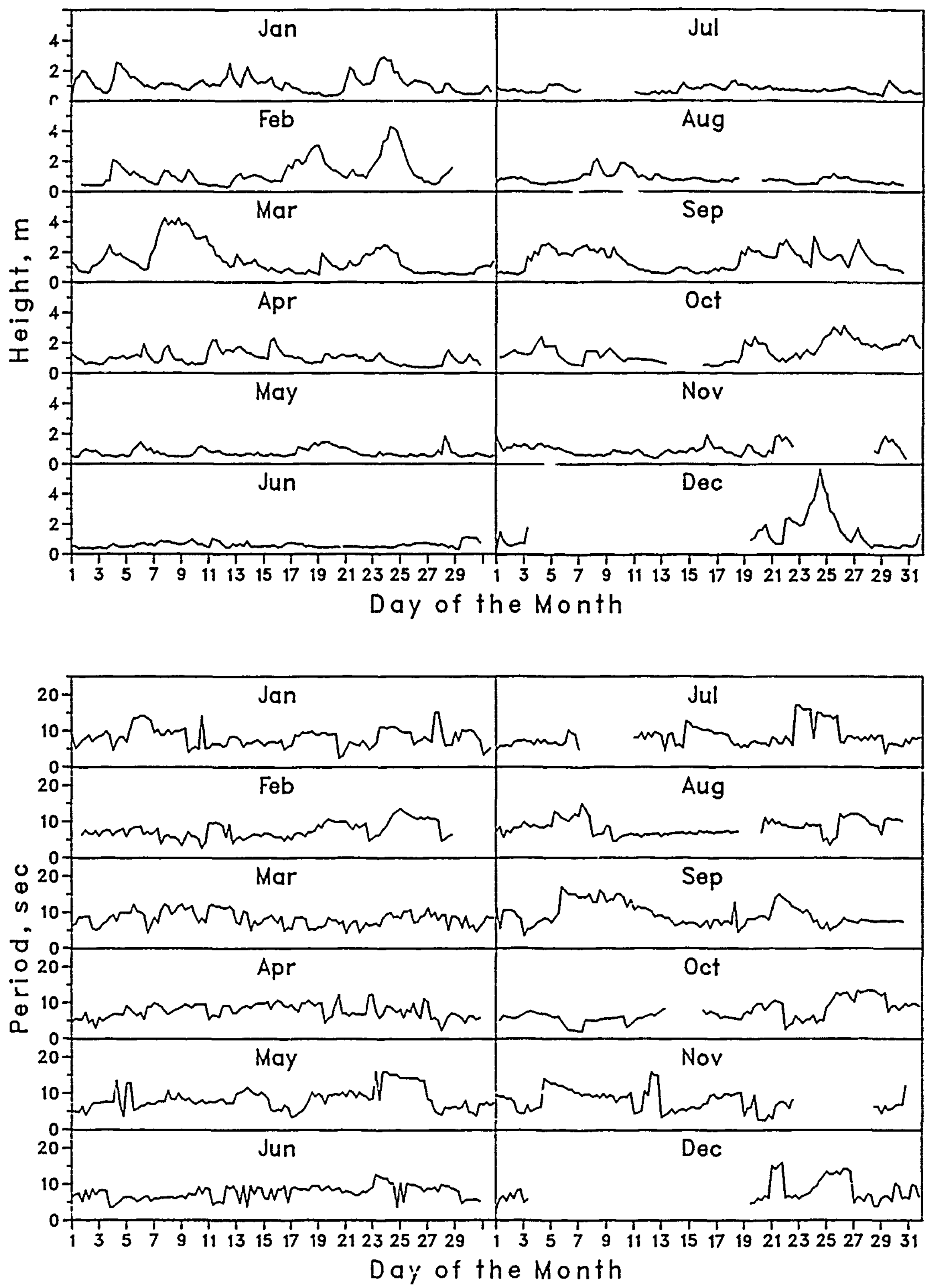


Figure 9. 1989 Time-histories of wave height and period for Gage 630

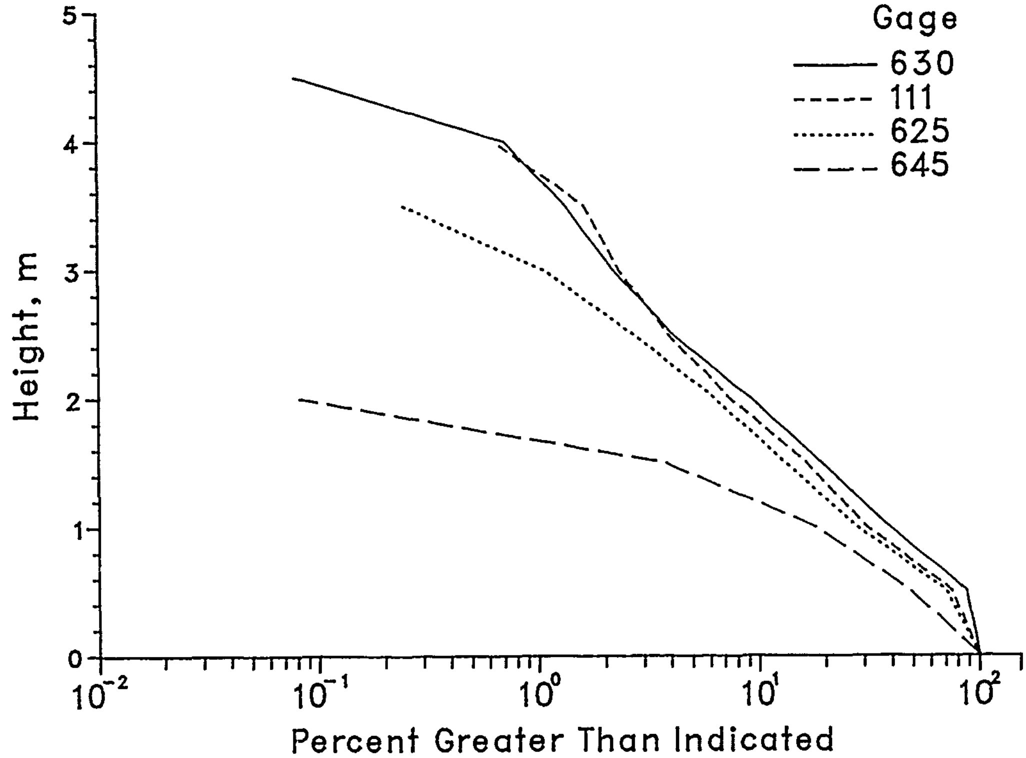


Figure 10. 1989 annual wave height distributions

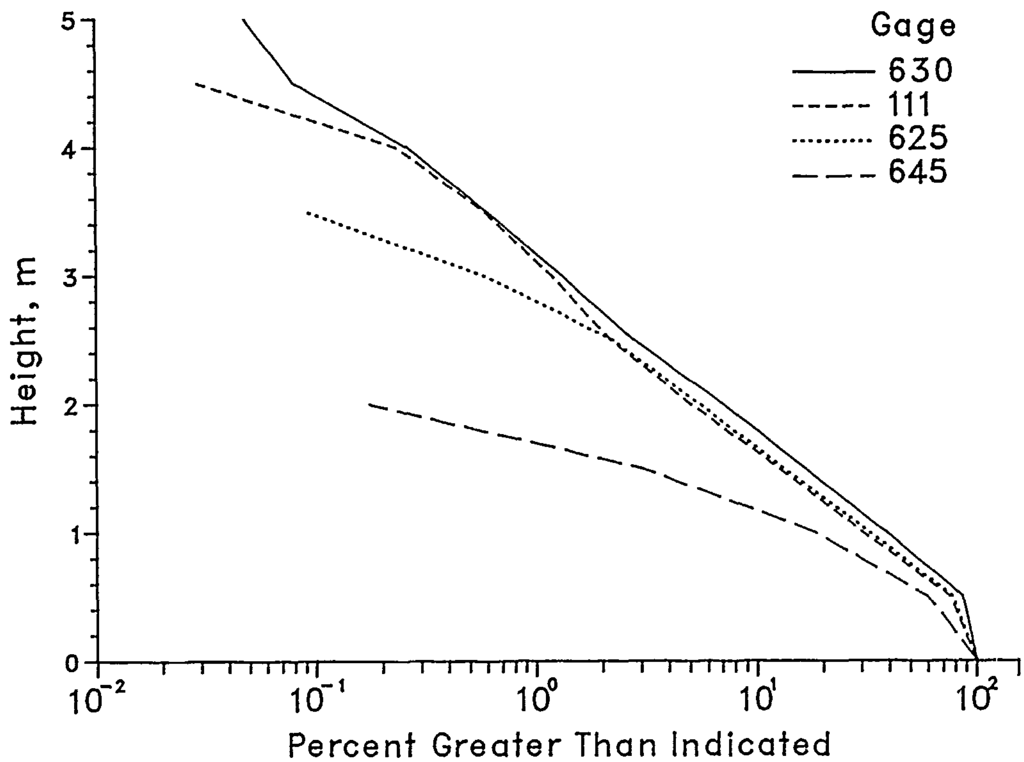


Figure 11. Annual distribution of wave heights for 1980 through 1989

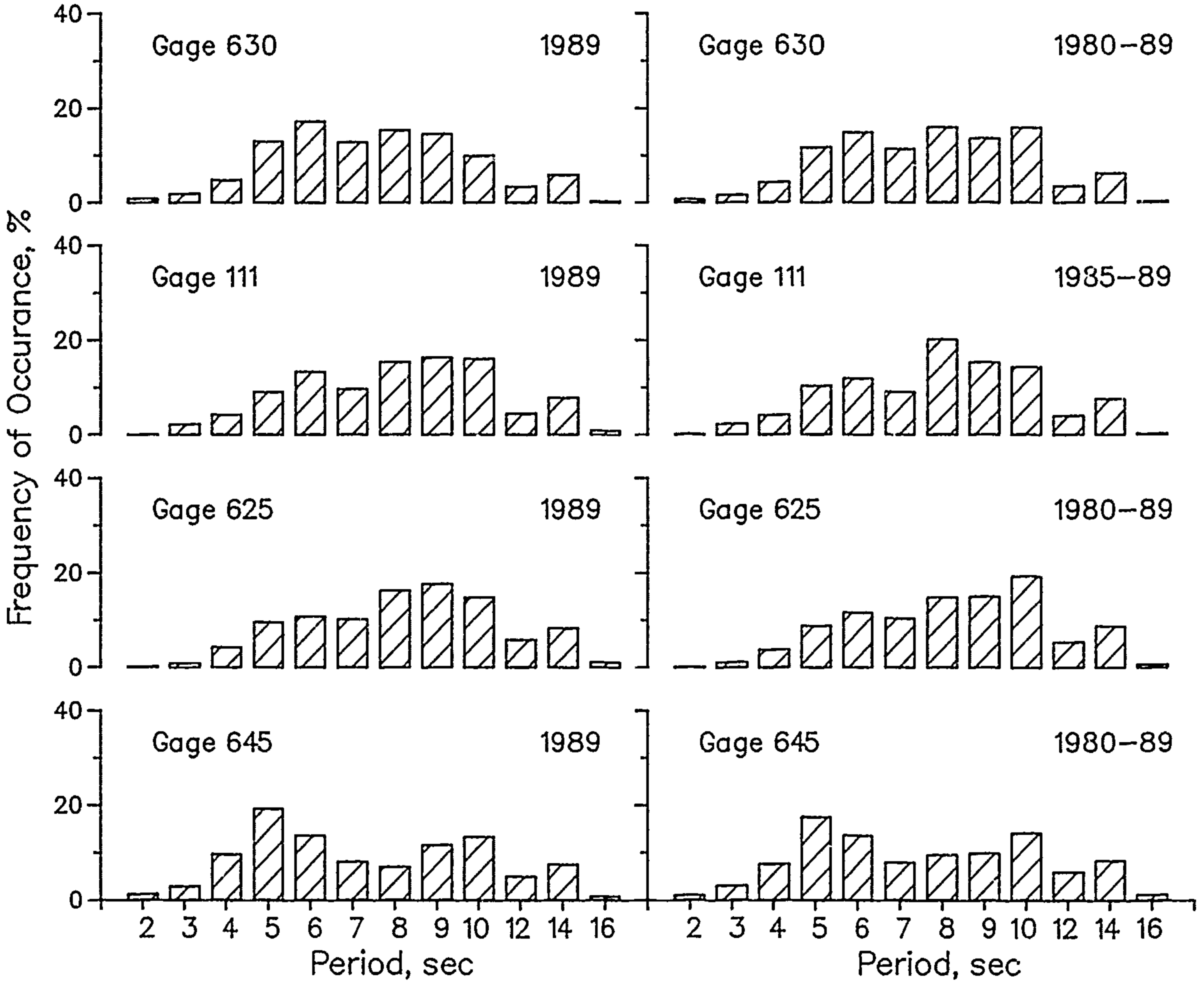


Figure 12. Annual wave period distributions for all gages

41. Summary wave statistics for the current year and all years combined are presented for Gage 630 in Table 3.

Table 3

Wave Statistics for Gage 630

	1989							1980-1989						
	Height				Period			Height				Period		
Month	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.
Jan	1.2	0.6	2.9	23	8.2	2.6	121	1.2	0.7	4.5	1983	8.0	2.8	1071
Feb	1.3	0.9	4.3	24	7.6	2.3	105	1.2	0.7	5.1	1987	8.4	2.6	1010
Mar	1.5	1.0	4.2	7	8.2	2.1	123	1.2	0.7	4.7	1983	8.6	2.6	1121
Apr	1.0	0.5	2.3	15	7.7	2.0	117	1.1	0.6	5.2	1988	8.6	2.7	1092
May	0.8	0.3	1.8	28	8.4	3.1	122	0.9	0.5	3.3	1986	8.1	2.4	1105
Jun	0.6	0.2	1.1	29	7.6	2.0	118	0.7	0.4	2.4	1988	7.7	2.2	1045
Jul	0.8	0.3	1.4	29	8.5	2.9	109	0.7	0.3	2.1	1985	8.1	2.5	1057
Aug	0.9	0.4	2.1	8	8.4	2.2	112	0.8	0.5	3.6	1981	8.0	2.4	1061
Sep	1.5	0.7	3.0	24	9.6	3.2	111	1.1	0.6	6.1	1985	8.6	2.7	1071
Oct	1.5	0.7	3.1	26	7.7	2.9	83	1.2	0.7	4.3	1982	8.7	2.8	1122
Nov	1.0	0.4	1.9	21	8.0	3.0	97	1.1	0.6	4.1	1981	7.9	2.8	958
Dec	1.5	1.2	5.6	24	8.1	3.3	59	1.2	0.8	5.6	1989	8.3	3.0	946
Annual	1.1	0.7	5.6	Dec	8.2	2.7	1277	1.0	0.6	6.1	Sep 1985	8.3	2.6	12659

42. Annual joint distributions of wave height versus wave period for Gage 630 are presented for all years combined in Table 5, and for 1989 in Table 4. Similar distributions for the other gages are included in Appendixes B-E.

43. Annual distributions of wave directions (relative to True North) based on daily observations of direction at the seaward end of the pier and height from Gage 625 (or Gage 111 when data for Gage 625 were unavailable) are shown in Figure 13. Monthly wave "roses" for 1989 and all years combined are presented in Figures 14 and 15, respectively.

Table 4

Annual (1989) Joint Distribution of H_{mo} versus T_p for Gage 630*

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	47	.	31	102	94	141	337	251	125	23	55	.	1206
0.50 - 0.99	31	188	258	626	807	619	752	767	509	125	243	16	4941
1.00 - 1.49	.	.	188	368	446	258	180	227	149	70	39	.	1925
1.50 - 1.99	.	.	8	188	227	149	94	125	78	47	86	8	1010
2.00 - 2.49	.	.	.	16	149	31	125	47	23	55	63	.	509
2.50 - 2.99	.	.	.	.	.	47	31	16	31	8	55	.	188
3.00 - 3.49	.	.	.	.	.	39	8	8	16	8	8	.	87
3.50 - 3.99	.	.	.	.	.	.	8	.	39	.	16	.	63
4.00 - 4.49	.	.	.	.	.	.	.	16	16	8	23	.	63
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	8	.	.	.	8
Total	78	188	485	1300	1723	1284	1535	1457	994	344	588	24	

* Percent occurrence (x100) of height and period.

Table 5

Annual (1980-1989) Joint Distribution of H_{mo} versus T_p for Gage 630 (All Years)*

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	30	16	28	66	94	118	118	329	193	70	126	3	1351
0.50 - 0.99	38	134	254	512	596	525	525	849	781	149	216	15	4791
1.00 - 1.49	.	9	140	398	450	264	264	239	339	42	122	4	2210
1.50 - 1.99	.	.	13	159	253	113	113	81	133	36	78	5	947
2.00 - 2.49	.	.	2	25	85	70	70	57	66	32	43	2	424
2.50 - 2.99	.	.	.	1	8	33	33	18	37	10	26	.	149
3.00 - 3.49	.	.	.	.	1	12	12	14	17	5	9	.	71
3.50 - 3.99	.	.	.	.	.	1	1	6	13	4	5	.	35
4.00 - 4.49	.	.	.	.	.	.	.	2	8	2	4	.	19
4.50 - 4.99	.	.	.	.	.	.	.	.	2	.	.	.	3
5.00 - Greater	.	.	.	.	.	.	.	1	1	2	1	.	5
Total	68	159	437	1161	1487	1136	1596	1360	1590	352	630	29	

* Percent occurrence (x100) of height and period.

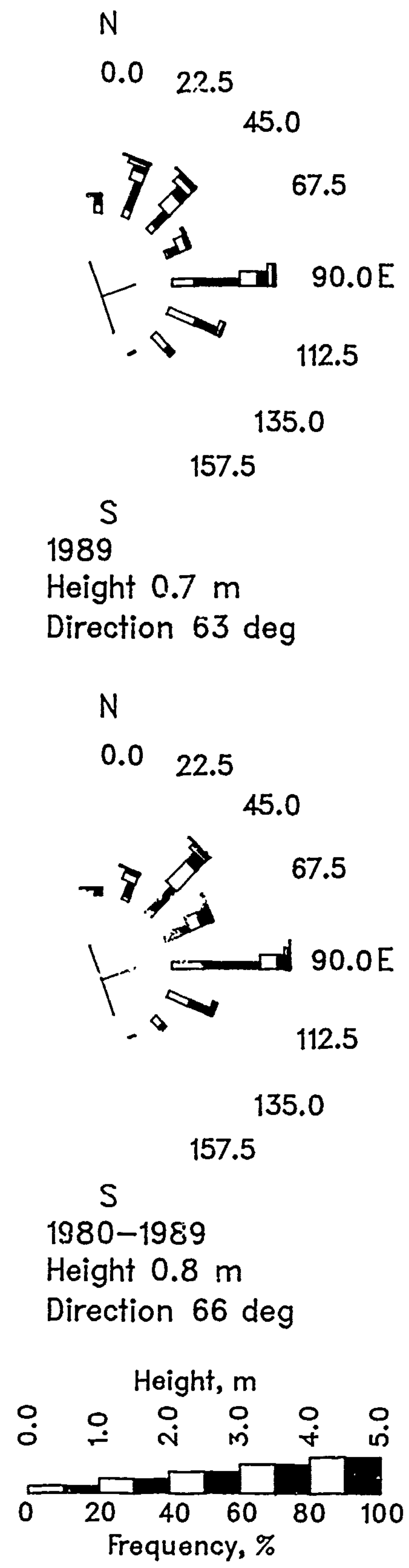


Figure 13. Annual wave roses

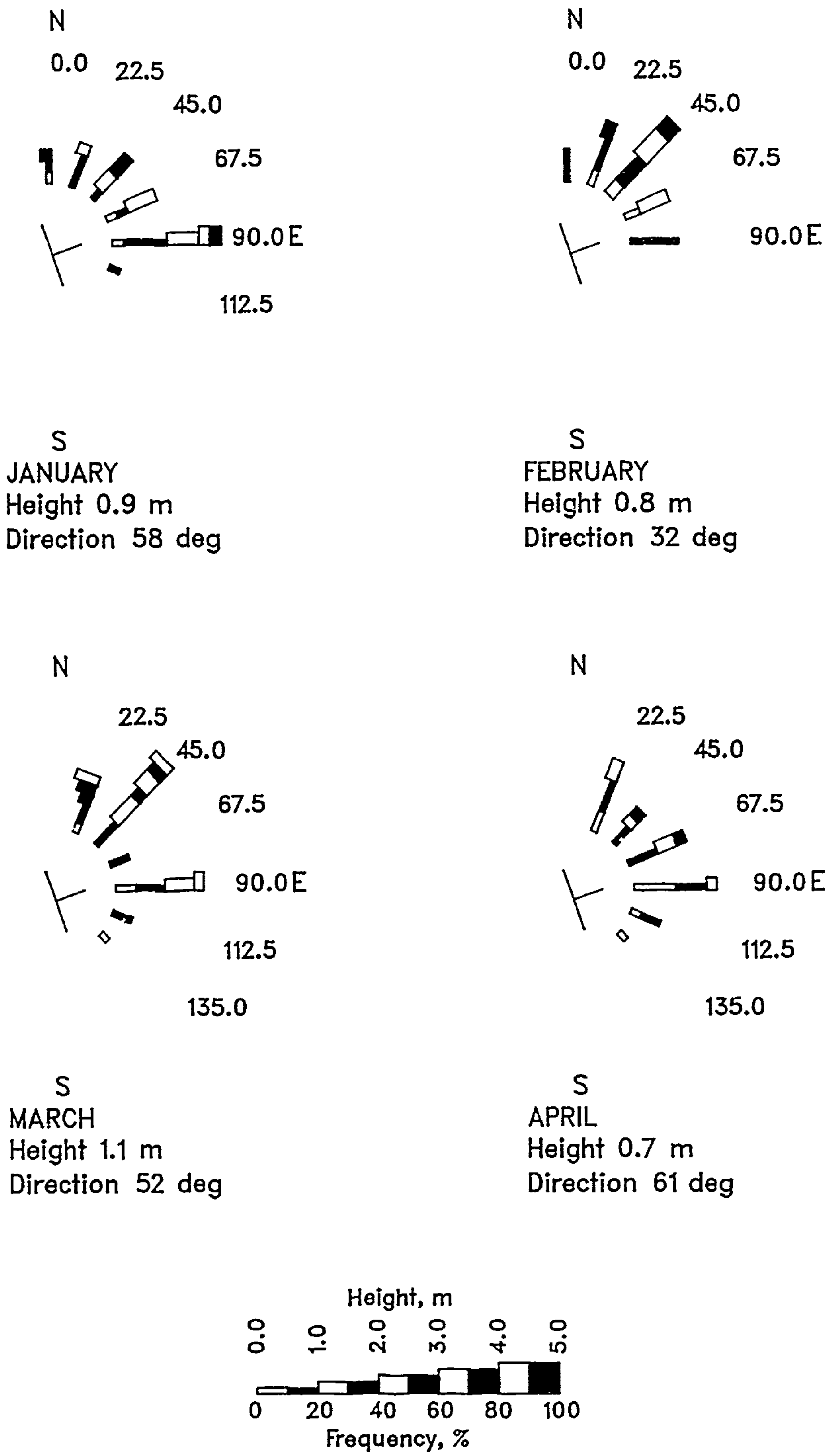


Figure 14. Monthly wave roses for 1989 (Sheet 1 of 3)

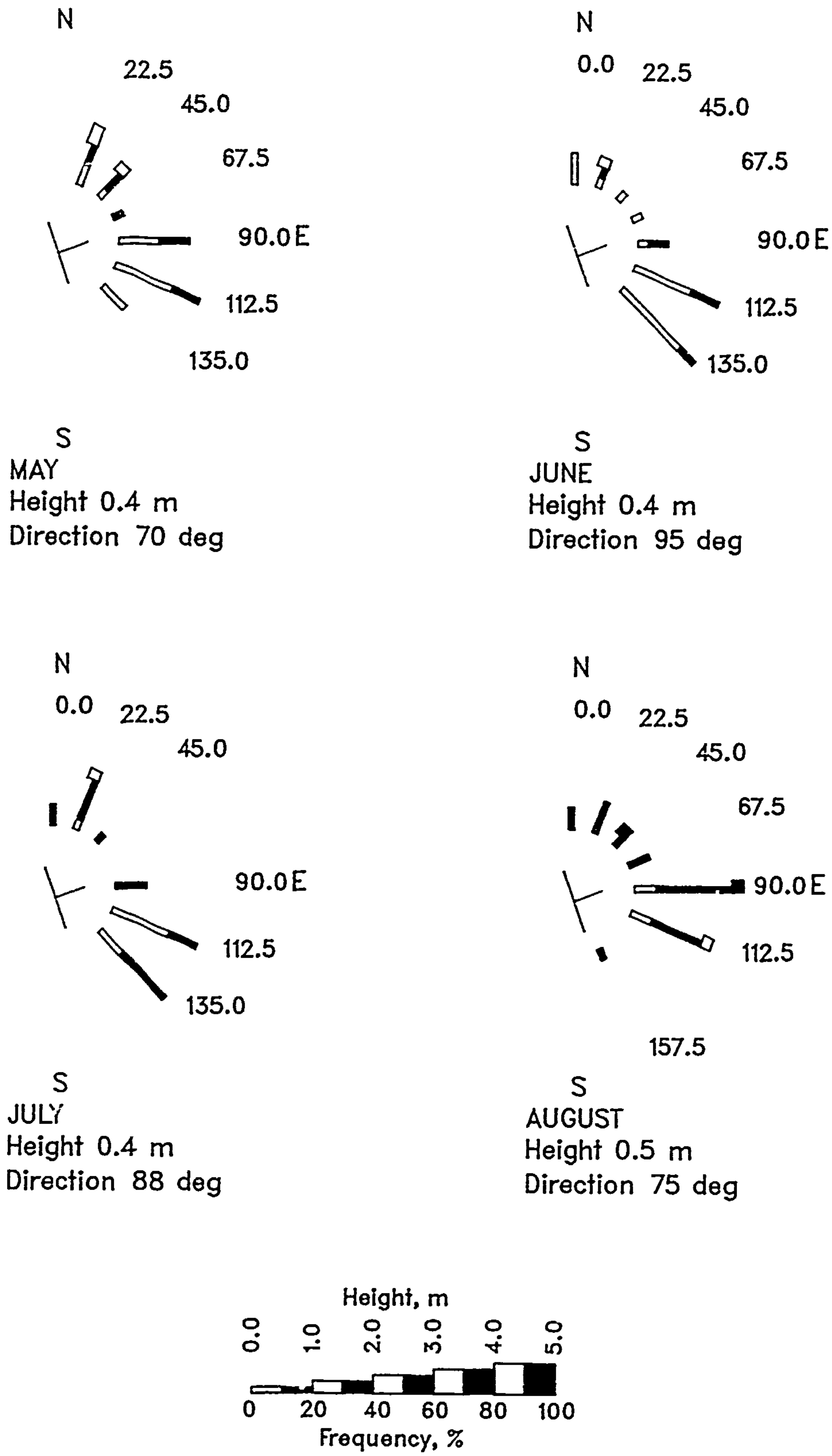


Figure 14. (Sheet 2 of 3)

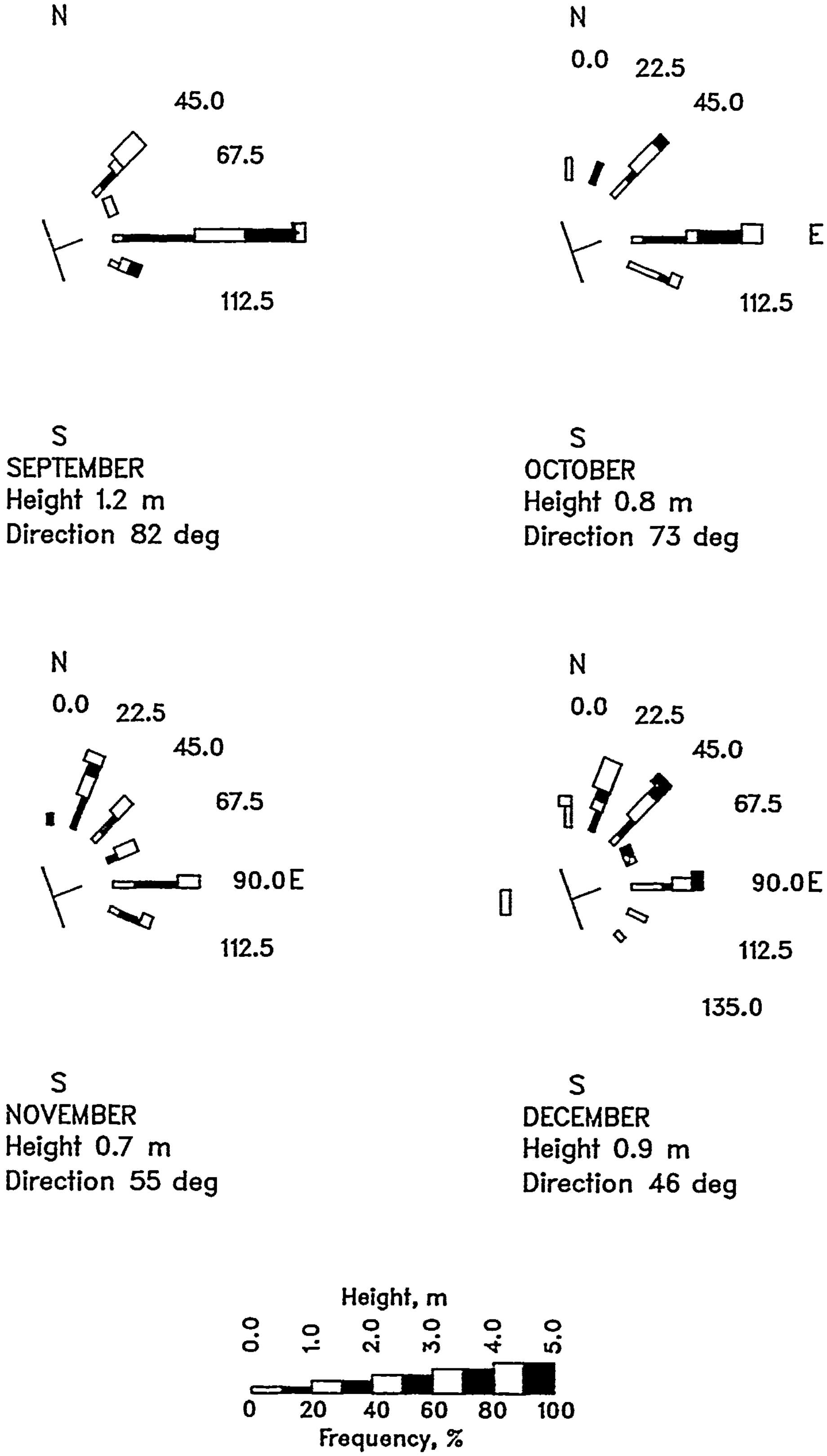


Figure 14. (Sheet 3 of 3)

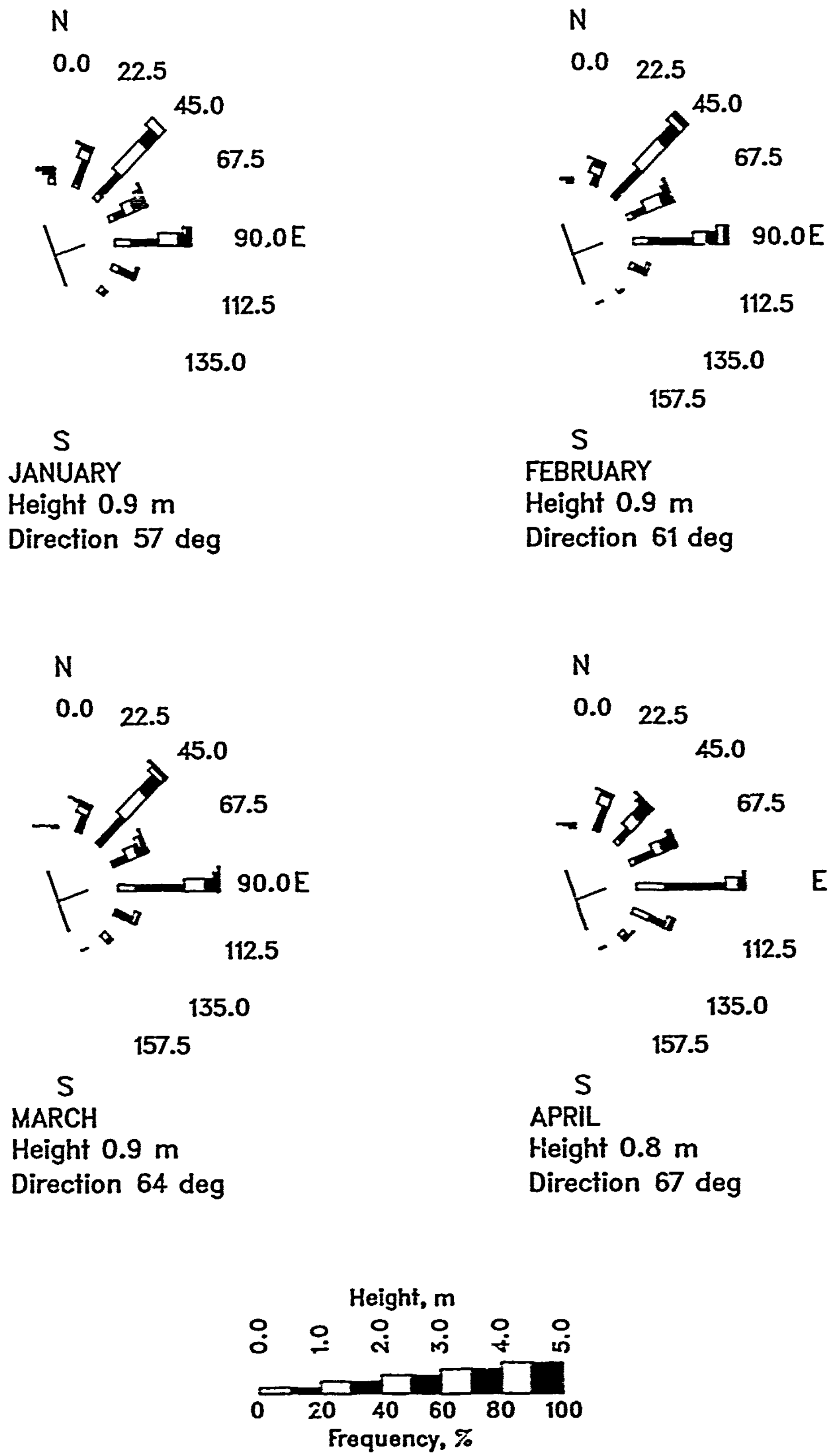


Figure 15. Monthly wave roses for 1980 through 1989 (Sheet 1 of 3)

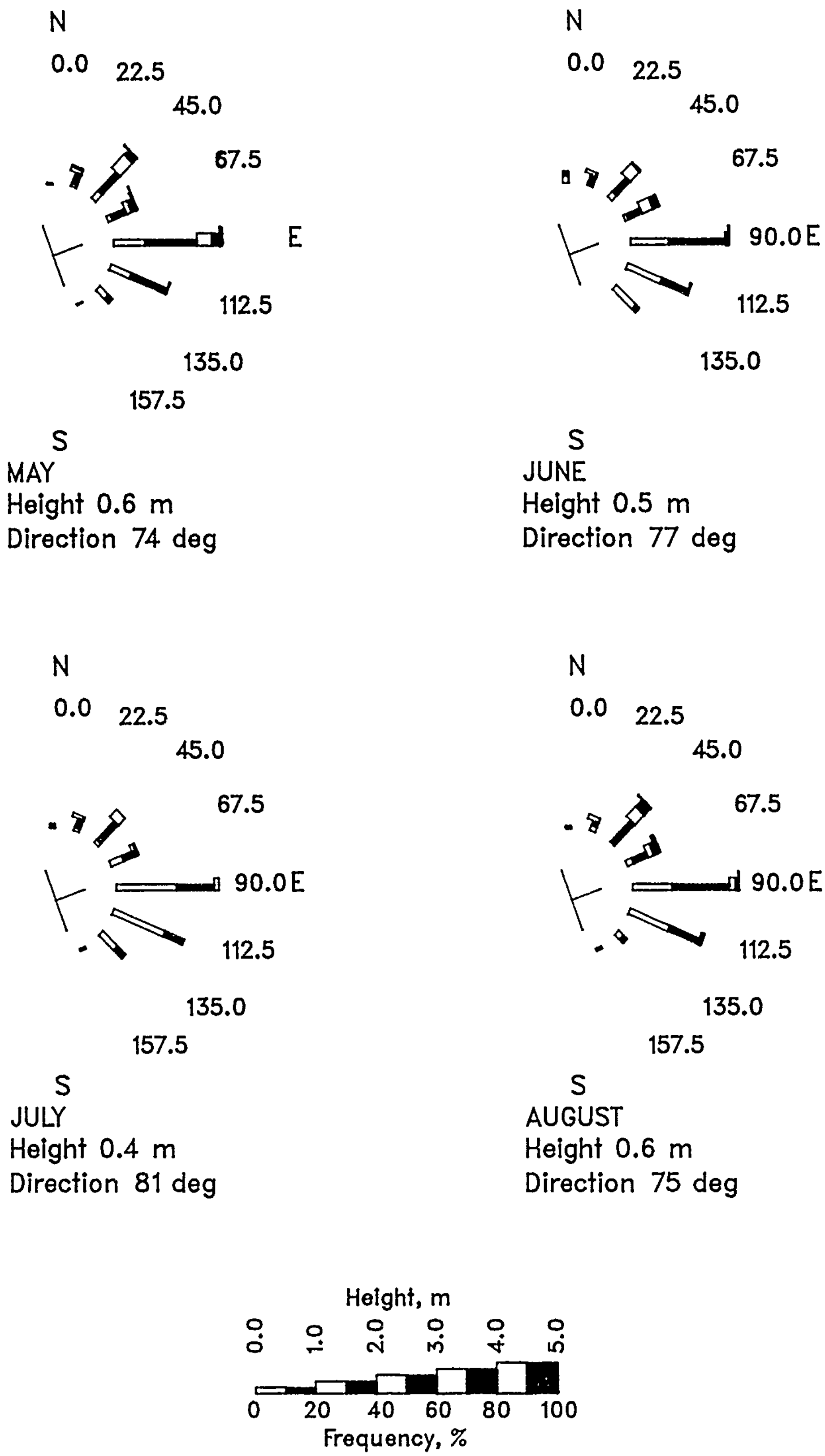


Figure 15. (Sheet 2 of 3)

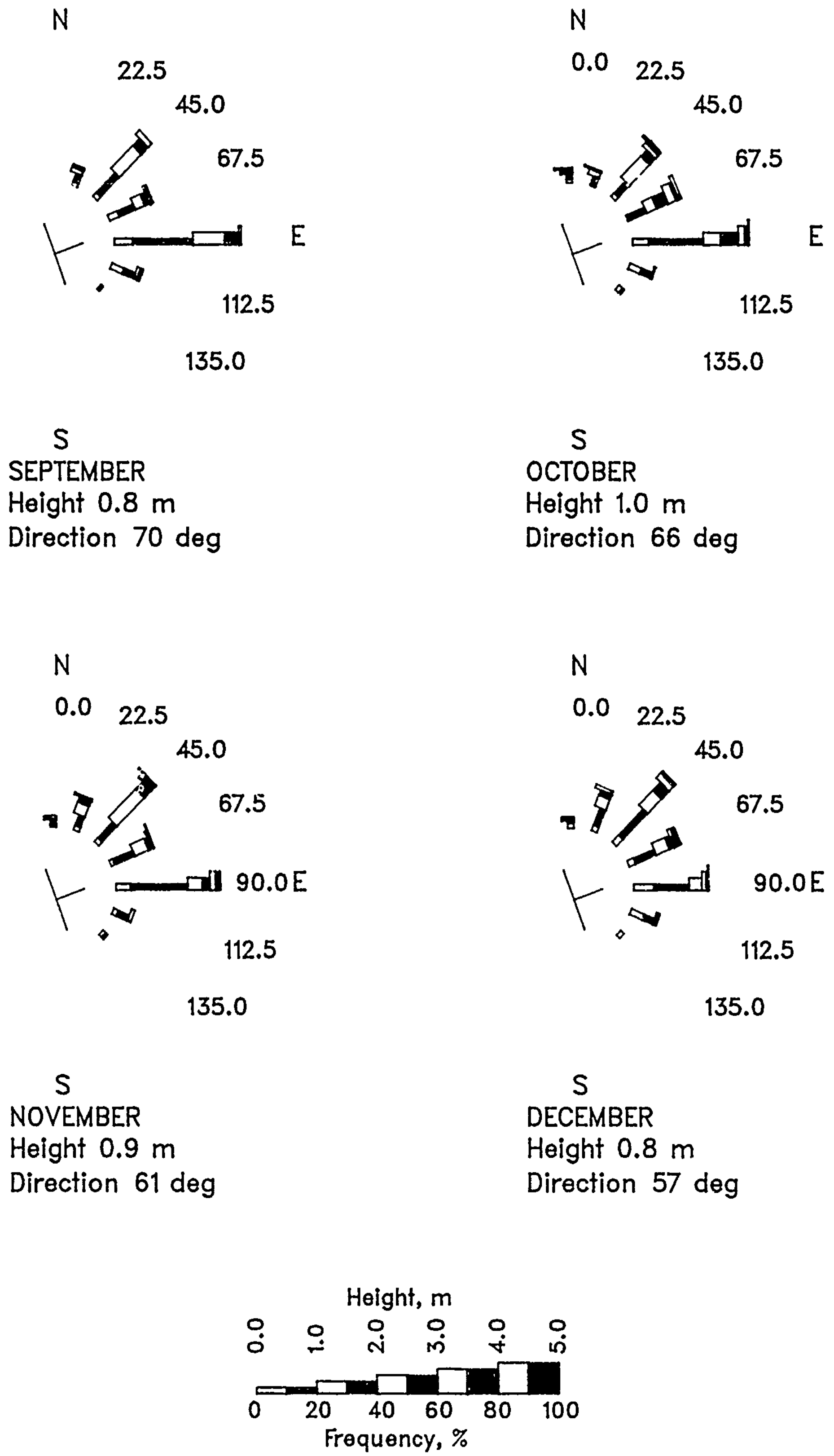


Figure 15 (Sheet 3 of 3)

PART IV: CURRENTS

44. Surface current speed and direction at the FRF are influenced by winds, waves, and, indirectly, by the bottom topography. The extent of the respective influence varies daily. However, winds tend to dominate the currents at the seaward end of the pier, whereas waves dominate within the surf zone.

Observations

45. Near 0700 EST, daily observations of surface current speed and direction were made at (a) the seaward end of the pier, (b) the midsurf position on the pier, and (c) 10 to 15 m from the beach 500 m updrift of the pier. Surface currents were determined by observing the movement of dye on the water surface.

Results

46. Annual mean and mean currents for 1980 through 1989 are presented in Table 6 and in Figure 16. Figure 16 shows the daily and average annual measurements at the beach, pier midsurf, and pier end locations. Since the relative influences of the winds and waves vary with position from shore, the current speeds and, to some extent, direction vary at the beach, midsurf, and pier end locations. Magnitudes generally are largest at the midsurf location and lowest at the end of the pier.

Table 6

Mean Longshore Surface Currents*

Month	Pier End, cm/sec 1989	Pier End, cm/sec 1980-1989	Pier Midsurf, cm/sec 1989	Pier Midsurf, cm/sec 1980-1989	Beach, cm/sec 1989	Beach, cm/sec 1980-1989
Jan	15	16	12	19	10	13
Feb	17	18	23	12	13	12
Mar	16	16	8	14	1	13
Apr	12	11	7	1	-5	7
May	-1	10	-9	-4	-7	-1
Jun	9	6	-6	-8	-17	-6
Jul	12	4	-6	-15	-19	-10
Aug	8	8	-8	-12	-8	-6
Sep	-1	7	-22	-8	-30	-4
Oct	10	9	13	1	24	4
Nov	6	13	-5	6	10	11
Dec	24	15	55	18	35	11
Annual	11	11	5	2	1	4

* + = southward; - = nortnward.

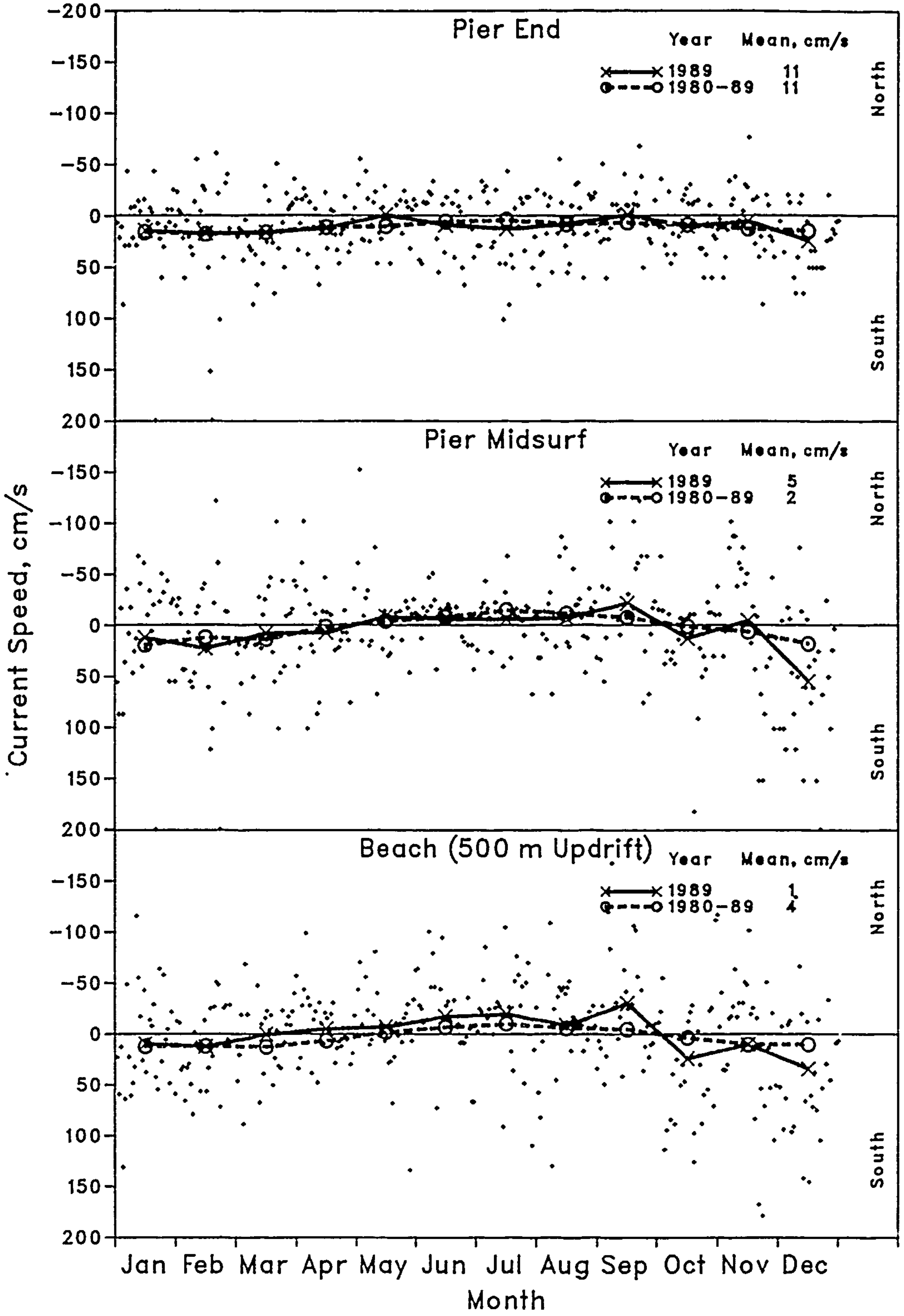


Figure 16. Daily current speeds and directions with monthly means for 1989

PART V: TIDES AND WATER LEVELS

Measurement Instrument

47. Water level data were obtained from a NOAA/NOS control tide station (sta 865-1370) located at the seaward end of the research pier (Figure 2) by using a Leupold and Stevens, Inc. (Beaverton, OR), digital tide gage. This analog-to-digital recorder is a float-activated, negator-spring, counterpoised instrument that mechanically converts the vertical motion of a float into a coded, punched paper tape record. The below-deck installation at pier sta 19+60 consisted of a 30.5-cm-diam stilling well with a 2.5-cm orifice and a 21.6-cm-diam float.

48. Operation and tending of the tide gage conformed to NOS standards. The gage was checked daily for proper operation of the punch mechanism and for accuracy of the time and water level information. The accuracy was determined by comparing the gage level reading with a level read from a reference electric tape gage. Once a week, a heavy metal rod was lowered down the stilling well and through the orifice to ensure free flow of water into the well. During the summer months, when biological growth was most severe, divers inspected and cleaned the orifice opening as required.

49. The tide station was inspected quarterly by a NOAA/NOS tide field group. Tide gage elevation was checked using existing NOS control positions, and the equipment was checked and adjusted as needed. Both NOS and FRF personnel also reviewed procedures for tending the gage and handling the data. Any specific comments on the previous months of data were discussed to ensure data accuracy.

50. Digital paper tape records of tide heights taken every 6 min were analyzed by the Tides Analysis Branch of NOS. An interpreter created a digital magnetic computer tape from the punch paper tape, which was then processed on a large computer. First, a listing of the instantaneous tidal height values was created for visual inspection. If errors were encountered, a computer program was used to fill in or recreate bad or missing data using correct values from the nearest NOS tide station and accounting for known time lags and elevation anomalies. The data were plotted, and a new listing was generated and rechecked. When the validity of the data had been confirmed, monthly tabulations of daily highs and lows, hourly heights (instantaneous

height selected on the hour), and various extreme and/or mean water level statistics were computed.

Results

51. Tides at the FRF are semidiurnal with both daily high and low tides approximately equal. Tide height statistics are presented in Table 7. Figure 17 plots the monthly tide statistics for all available data, and Figure 18 compares the distribution of daily high and low water levels and hourly tide heights. The monthly or annual mean sea level (MSL) reported is the average of the hourly heights, whereas the mean tide level is midway between mean high water (MHW) and mean low water (MLW), which are the averages of the daily high- and low-water levels, respectively, relative to NGVD. Mean range (MR) is the difference between MHW and MLW levels, and the lowest water level for the month is the extreme low (EL) water, while the highest water level is the extreme high (EH) water level.

Table 7

Tide Height Statistics*

Month or Year	Mean High Water	Mean Tide Level	Mean Sea Level	Mean Low Water	Mean Range	Extreme High	Date	Extreme Low	Date
					1989				
Jan	43	5	5	-34	77	81	8	-61	10
Feb	46	6	7	-34	80	102	24	-68	10
Mar	48	9	9	-30	78	109	8	-53	18
Apr	44	4	4	-37	81	88	7	-77	5
May	48	7	8	-34	82	76	7	-71	6
Jun	47	7	8	-33	80	76	30	-54	1
Jul	50	9	10	-30	80	77	1	-45	3
Aug	58	18	18	-22	80	88	19	-51	21
Sep	60	20	20	-20	80	102	19	-47	16
Oct	-	-	-	Gage	Inoperative	-	-	-	-
Nov	45	6	6	-34	79	76	10	-70	12
Dec	47	6	7	-34	81	117	13	-66	16
1989	49	9	9	-31	80	199	Mar	-77	Apr
					Prior Years				
1988	46	6	7	-33	79	129	Apr	-72	Dec
1987	55	15	16	-24	79	113	Jan	-63	Nov
1986	60	13	13	-35	95	123	Dec	-108	Jan
1985	59	10	11	-37	96	136	Dec	-93	Apr
1984	64	16	16	-32	97	147	Oct	-77	Jul
1983	68	19	19	-30	98	143	Jan	-73	Mar
1982	58	8	9	-42	99	127	Oct	-108	Feb
1981	59	8	9	-42	101	149	Nov	-110	Apr
1980	59	8	8	-43	102	118	Mar	-119	Mar
1979	60	9	9	-43	103	121	Feb	-95	Sep
1979-1989	59	11	12	-36	95	199	Mar 1989	-119	Mar 1980

* Measurements are in centimeters.

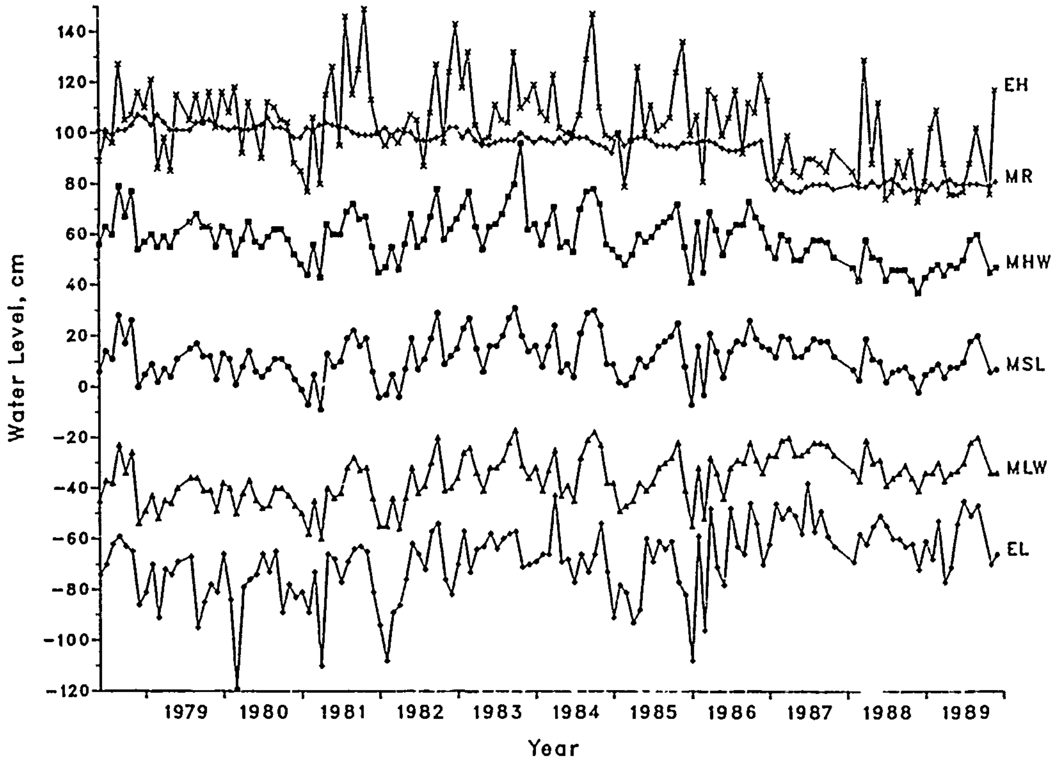


Figure 17. Monthly tide and water level statistics relative to NGVD

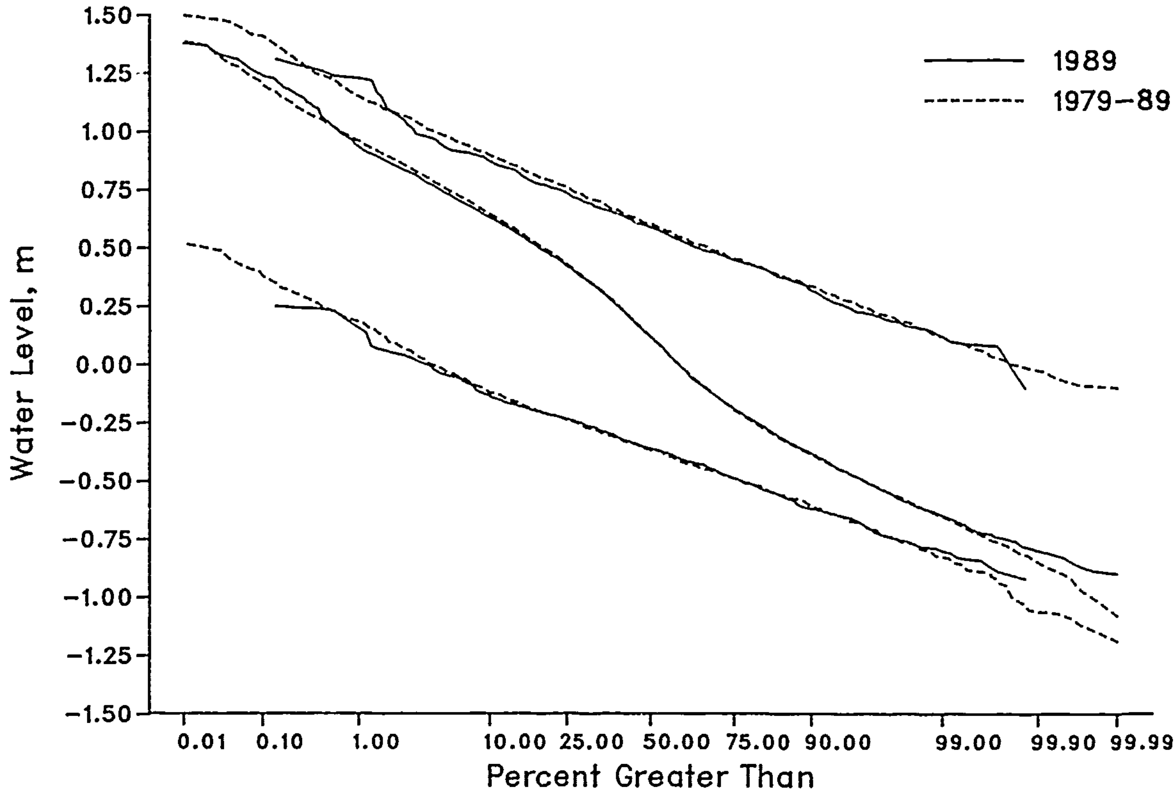


Figure 18. Distributions of hourly tide heights and high- and low-water levels

PART VI: WATER CHARACTERISTICS

52. Monthly averages of daily measurements of surface water temperature, visibility, and density at the seaward end of the FRF pier are given in Table 8. The summaries represent single observations made near 0700 EST and, therefore, may not reflect daily average conditions since such characteristics can change within a 24-hr period. Large temperature variations were common when there were large differences between the air and water temperatures and variations in wind direction. From past experience, persistent onshore winds move warmer surface water toward the shoreline, although offshore winds cause colder bottom water to circulate shoreward resulting in lower temperatures.

Table 8

Mean Surface Water Characteristics

Month	Temperature deg C 1989	Temperature deg C 1980-1989	Visibility m 1989	Visibility m 1980-1989	Density g/cm^3 1989	Density g/cm^3 1980-1989
Jan	7.5	5.8	1.9	1.2	1.0250	1.0236
Feb	7.3	4.9	2.1	1.7	1.0248	1.0232
Mar	6.4	6.5	1.2	1.5	1.0235	1.0230
Apr	11.2	10.9	1.9	1.9	1.0234	1.0227
May	15.5	15.2	2.9	2.4	1.0220	1.0222
Jun	19.0	19.3	4.1	3.5	1.0224	1.0216
Jul	23.6	21.9	2.6	3.7	1.0198	1.0215
Aug	25.6	23.4	2.5	3.1	1.0181	1.0205
Sep	24.4	22.8	1.3	2.2	1.0208	1.0211
Oct	21.6	19.2	1.8	1.5	1.0211	1.0217
Nov	16.5	14.9	1.4	1.0	1.0235	1.0230
Dec	7.7	9.9	0.7	1.1	1.0239	1.0235
Annual	15.6	14.5	2.0	2.1	1.0223	1.0223

Temperature

53. Daily sea surface water temperatures (Figure 19) were measured with an NOS water sampler and thermometer. Monthly mean water temperatures (Table 8) varied with the air temperatures (see Table 2).

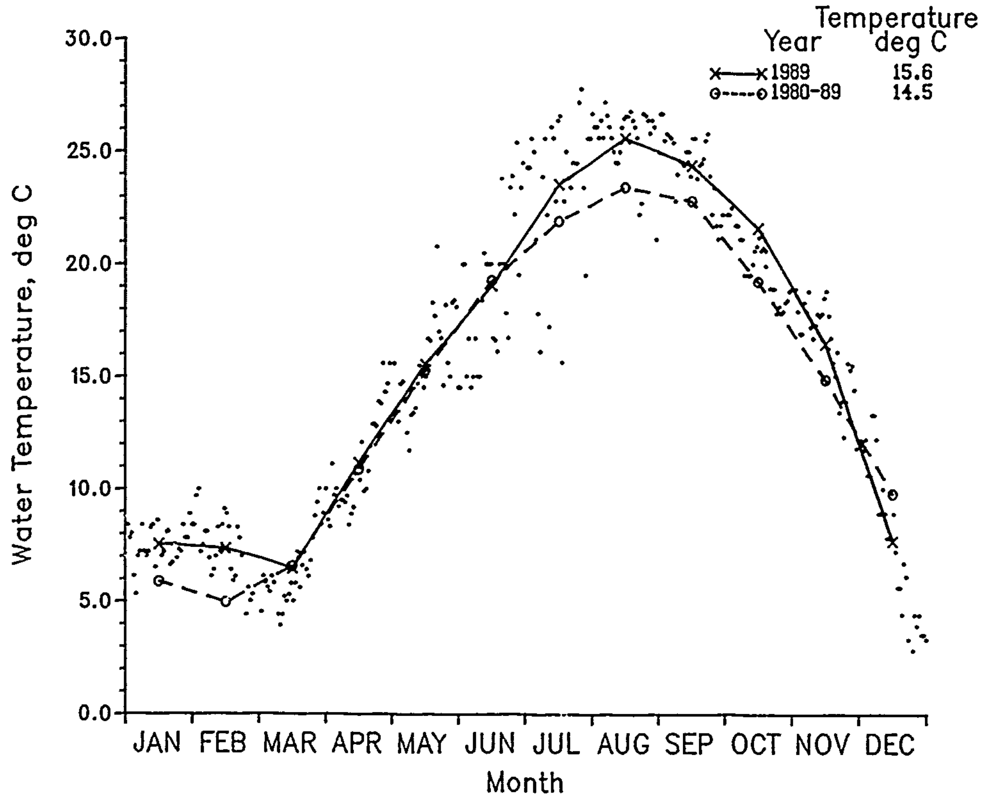


Figure 19. Daily water temperature values with monthly means

Visibility

54. Visibility in coastal nearshore waters depends on the amount of salts, soluble organic material, detritus, living organisms, and inorganic particles in the water. These dissolved and suspended materials change the absorption and attenuation characteristics of the water that vary daily and yearly.

55. Visibility was measured with a 0.3-m-diam Secchi disk, and similar to water temperature, variation was related to onshore and offshore winds. Onshore winds moved warm clear surface water toward shore, whereas offshore winds brought up colder bottom water with large concentrations of suspended matter. Figure 20 presents the daily and monthly mean surface visibility values for the year. Large variations were common, and visibility less than 1 m was expected in any month. Monthly means are given in Table 8.

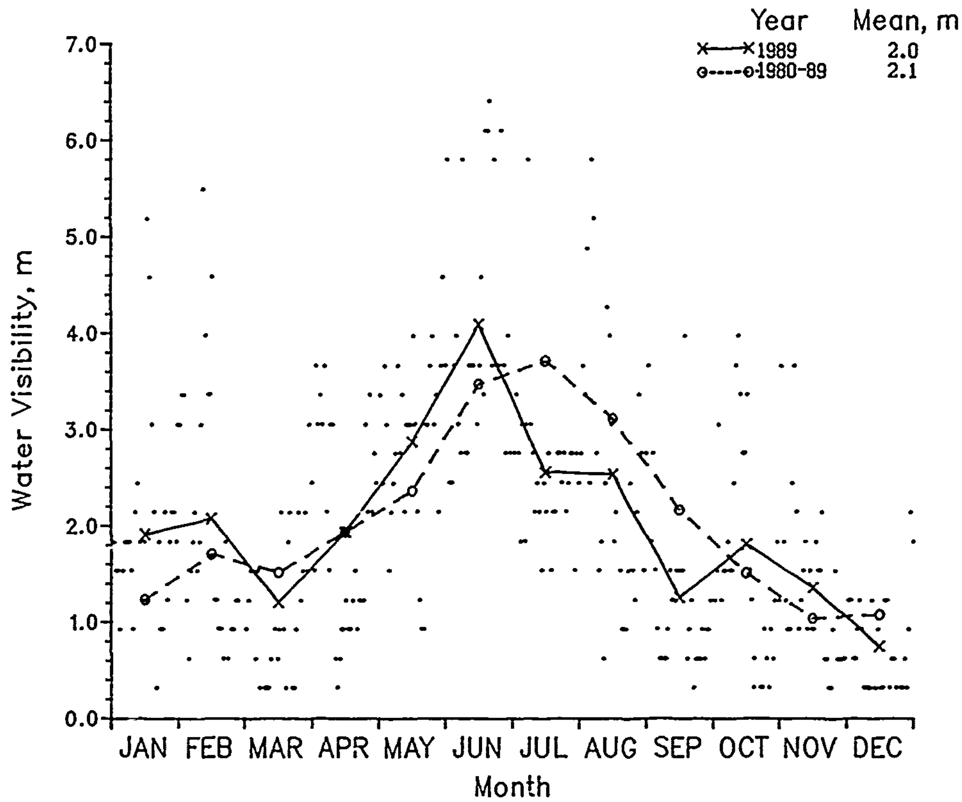


Figure 20. Daily water visibility values with monthly means

Density

56. Daily and monthly mean surface density values, plotted in Figure 21, were measured with a hydrometer. Monthly means are also given in Table 8.

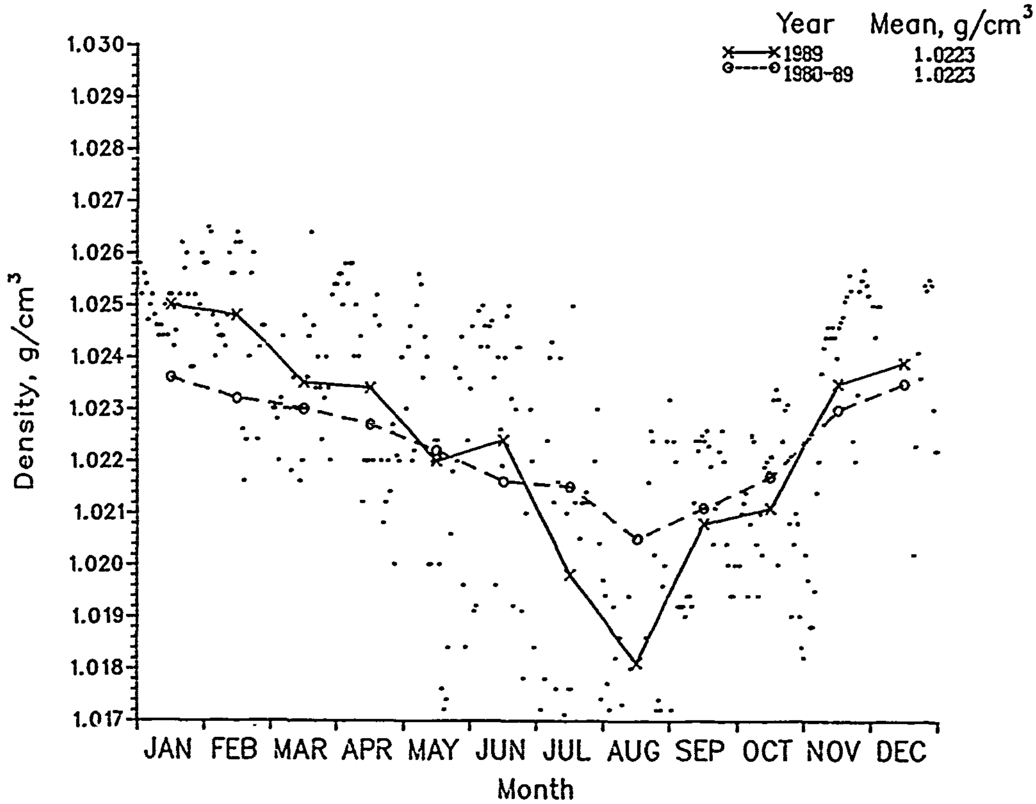


Figure 21. Daily water density values with monthly means

PART VII: SURVEYS

57. Waves and currents interacting with bottom sediments produce changes in the beach and nearshore bathymetry. These changes can occur very rapidly in response to storms or slowly as a result of persistent but less forceful seasonal variations in wave and current conditions.

58. Nearshore bathymetry at the FRF is characterized by regular shore-parallel contours, a moderate slope, and a barred surf zone (usually an outer storm bar in water depths of about 4.5 m and an inner bar in water depths between 1.0 and 2.0 m). This pattern is interrupted in the immediate vicinity of the pier where a permanent trough runs under much of the pier, ending in a scour hole where depths can be up to 3.0 m greater than the adjacent bottom (Figure 22). This trough, which apparently is the result of the interaction of waves and currents with the pilings, varies in shape and depth with changing wave and current conditions. The effect of the pier on shore-parallel contours occurs as far as 300 m away, and the shoreline may be affected up to 350 m from the pier (Miller, Birkemeier, and DeWall 1983).

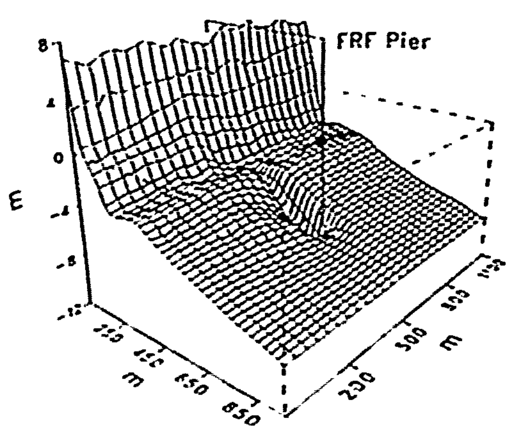


Figure 22. Permanent trough under the FRF pier, 27 February 89

59. To document the temporal and spatial variability in bathymetry, surveys were conducted approximately monthly of an area extending 600 m north and south of the pier and approximately 950 m offshore. Contour maps resulting from these surveys along with plots of change in elevation between surveys are given in Appendix A.

60. All surveys used the Coastal Research Amphibious Buggy (CRAB), a 10.7-m-tall amphibious tripod, and a Zeiss electronic surveying system described by Birkemeier and Mason (1984). The profile locations are shown in each figure in Appendix A. Survey accuracy was about ±3 cm horizontally and vertically. Monthly soundings along both sides of the FRF pier were collected by lowering a weighted measuring tape to the bottom and recording the distance below the pier deck. Soundings were taken midway between the pier pilings to minimize errors caused by scour near the pilings.

61. A history of bottom elevations below Gages 645 and 625 is presented in Figure 23 for their respective pier stations of sta 7+80 (238 m) and sta 19+00 (579 m) along with intermediate locations, 323 and 433 m.

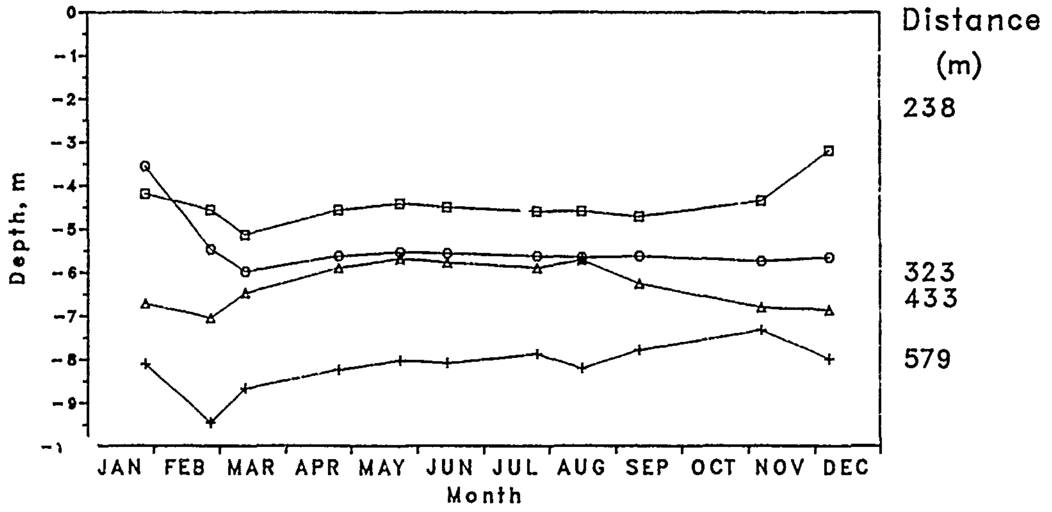


Figure 23. Time-history of bottom elevations at selected locations under the FRF pier

PART VIII: PHOTOGRAPHY

Aerial Photographs

62. Aerial photography was taken quarterly using a 23-cm aerial mapping camera at a scale of 1:12,000. All coverage was at least 60-percent overlap, with flights flown as closely as possible to low tide between 1000 and 1400 EST with less than 10-percent cloud cover. The flight lines covered are shown in Figure 24. Figure 25 is a sample of the imagery obtained on 17 April 1989; the available aerial photographs for the year are:

Date	Flight Lines	Format
5 Jan	2	Color
	3	B/W
11 Mar	1	B/W
	2	Color
17 Apr	2	Color
	3	B/W
30 Jul	1	B/W
	2	Color
	3	B/W
11 Oct	2	Color
	3	B/W

Beach Photographs

63. Daily color slides of the beach were taken using a 35-mm camera from the same location on the pier looking north and south (Figure 26). The location from which each picture was taken, as well as the date, time, and a brief description of the picture, was marked on the slides.

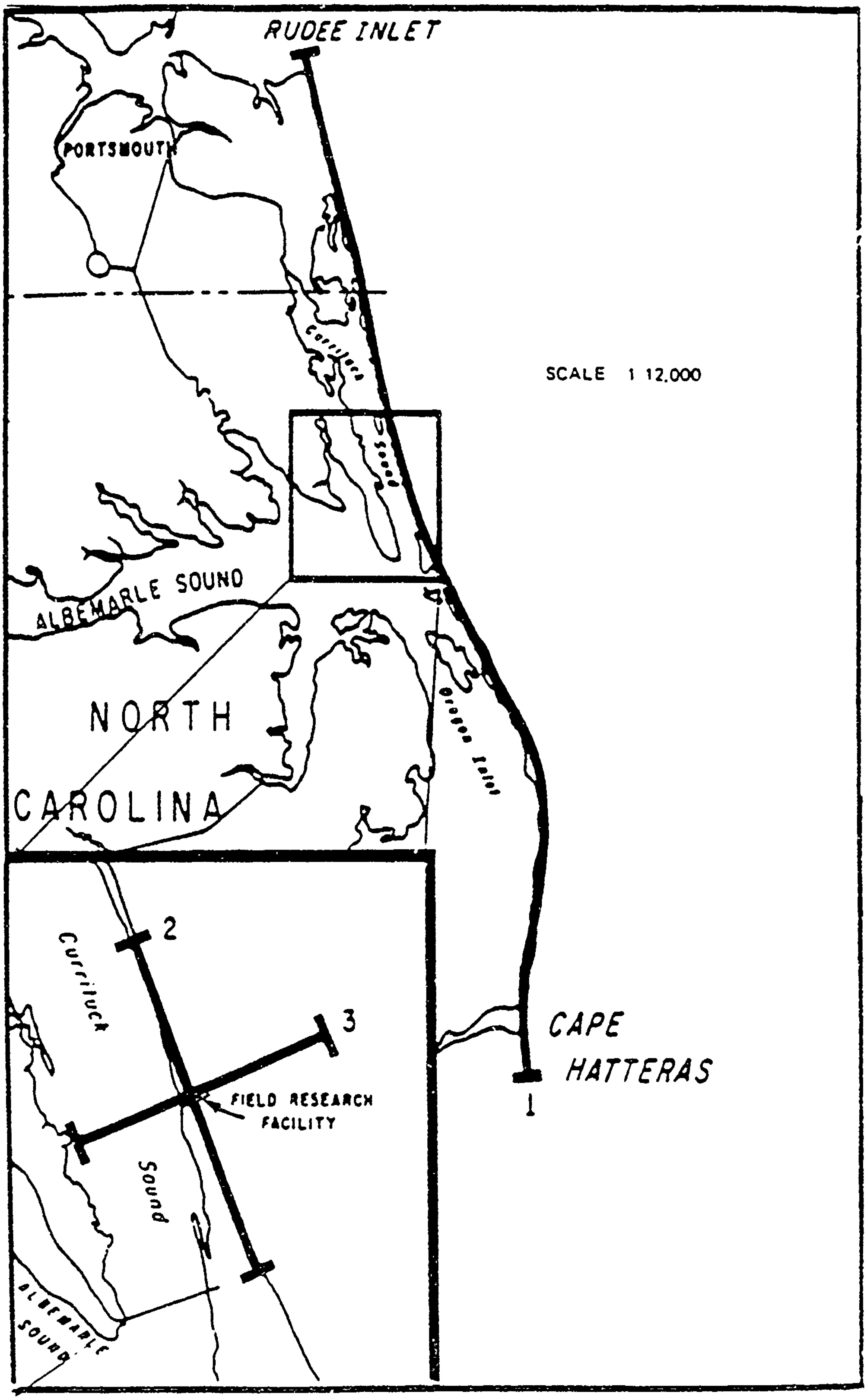


Figure 24. Aerial photography flight lines

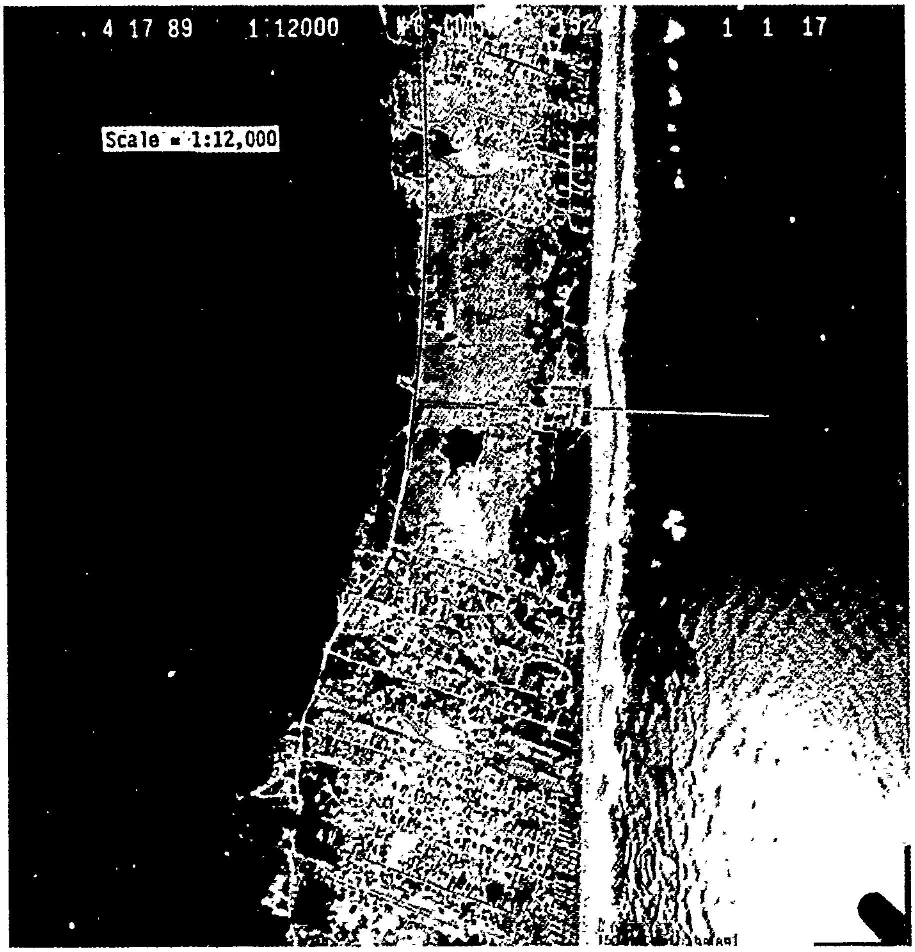
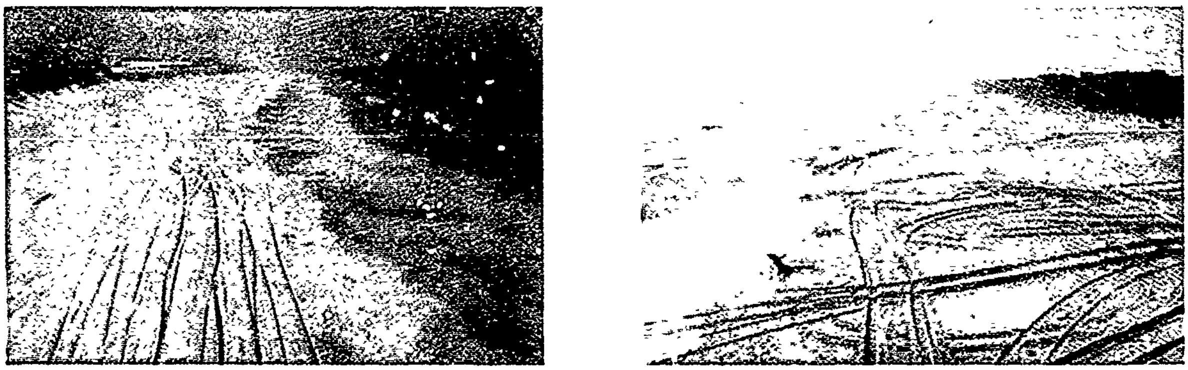


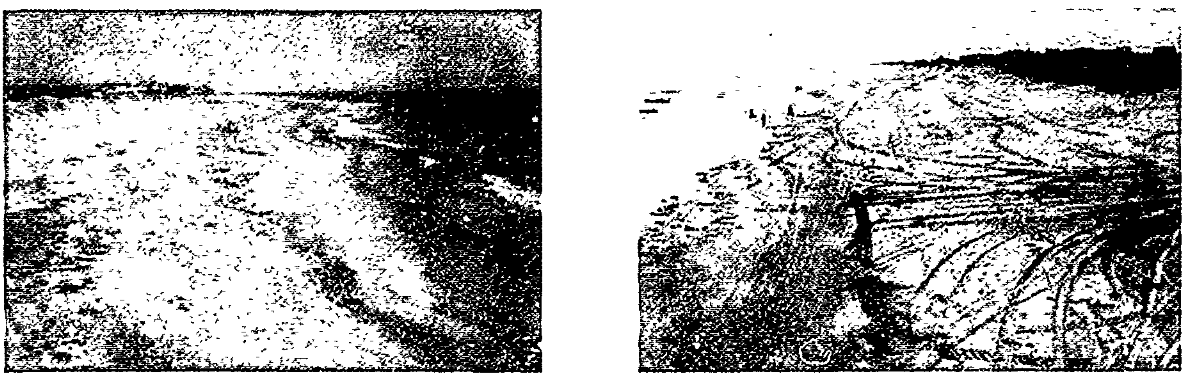
Figure 25. Sample aerial photograph, 17 April 1989

North View South View

a. 15 January 1989



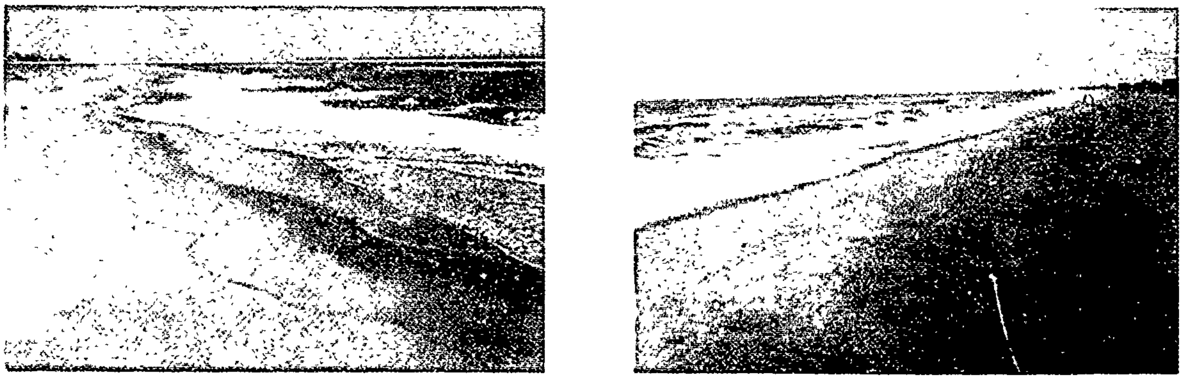
b. 2 February 1989



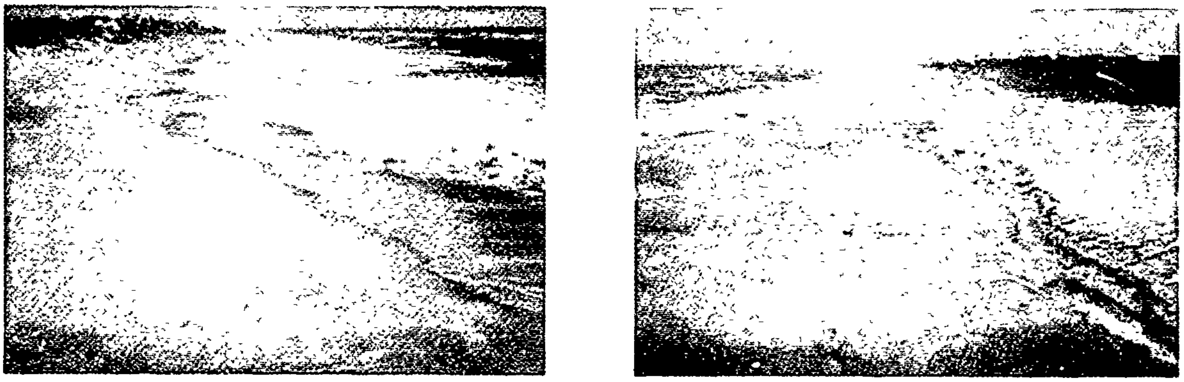
c. 18 March 1989

Figure 26. Beach photos looking north and south from the FRF pier (Sheet 1 of 4)

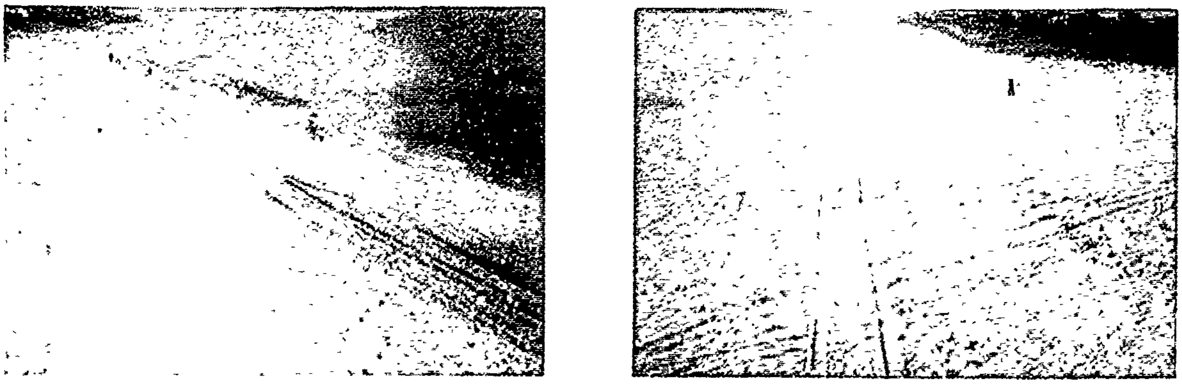
North View South View



d. 14 April 1989



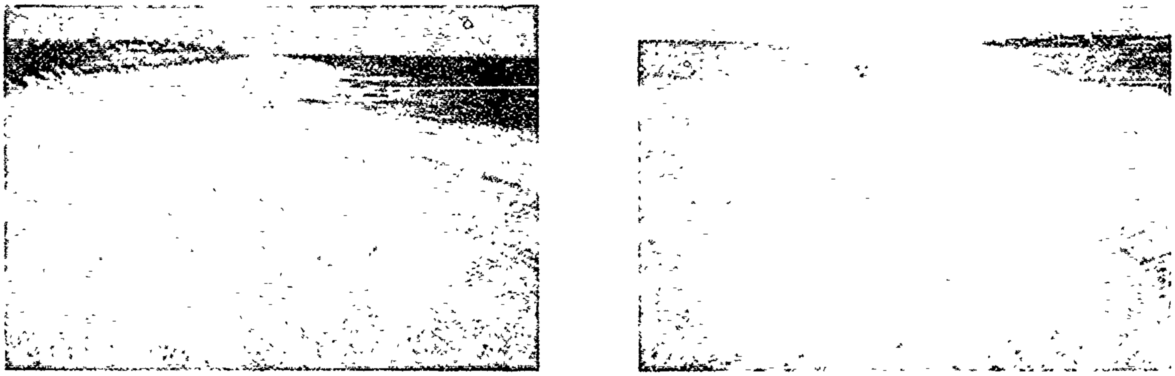
e. 19 May 1989



f. 23 June 1989

Figure 26. (Sheet 2 of 4)

North View South View



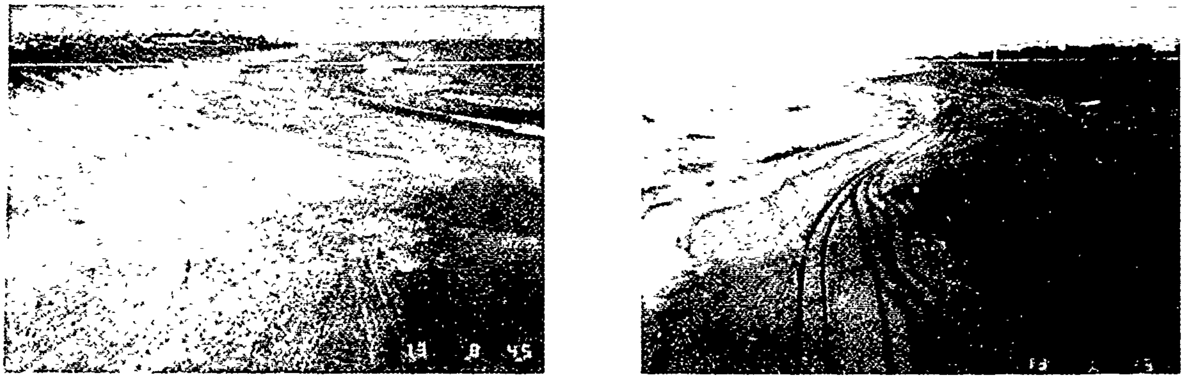
g. 14 July 1989

h. 22 August 1989

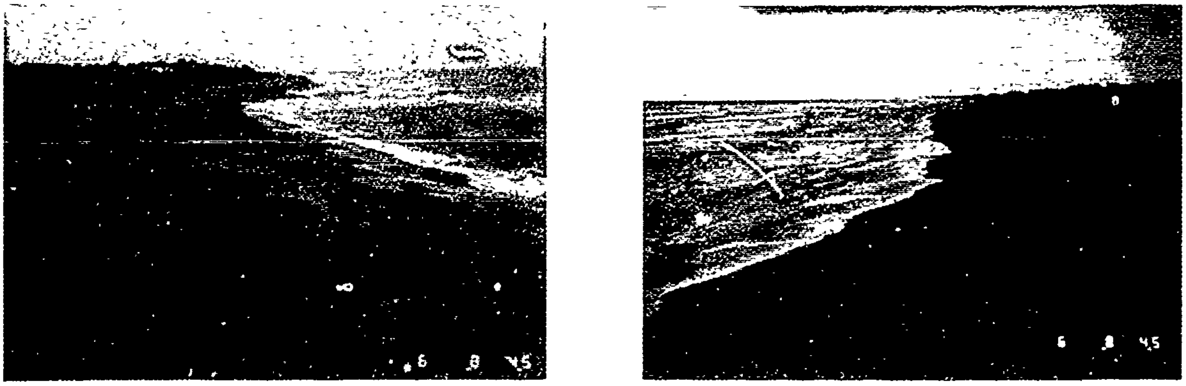
i. 14 September 1989

Figure 26. (Sheet 3 of 4)

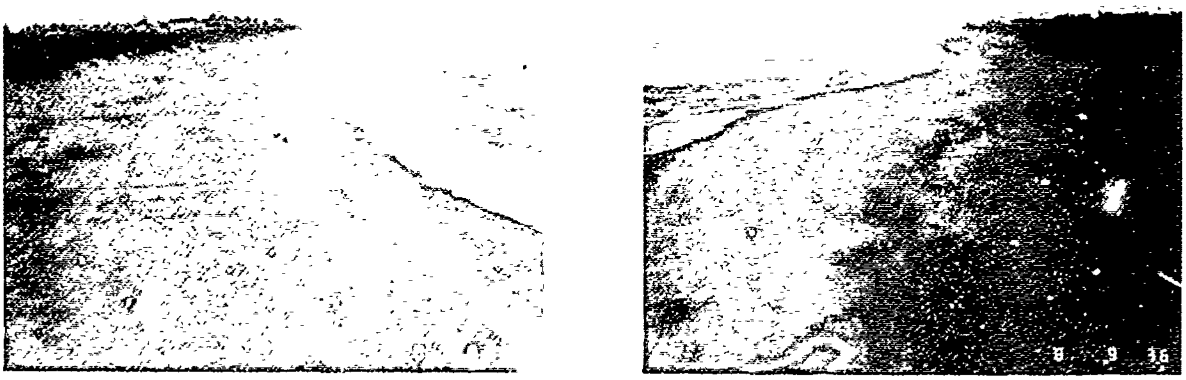
North View South View



j. 13 October 1989



k. 6 November 1989



l. 8 December 1989

Figure 26. (Sheet 4 of 4)

PART IX: STORMS

64. This section discusses storms (defined here as times when the wave height parameter, H_{mo} , equaled or exceeded 2 m at the seaward end of the FRF pier). Sample spectra from Gage 630 are given in Appendix B. Prestorm and/or poststorm bathymetry diagrams are given in Appendix A. Tracking information was provided by NOAA Daily Weather Maps (US Department of Commerce 1989).

4 January 1989 (Figure 27)

65. Dropping down from Canada on 3 January, this storm quickly intensified as it passed over Virginia into the Atlantic. Maximum wind speeds (from northwest) exceeded 13 m/sec on 4 January at 0242 EST, followed 6 hr later by the maximum H_{mo} (Gage 111) of 2.24 m (T_p = 7.11 sec). The minimum atmospheric pressure of 995 mb occurred on 3 January at 2042 EST. Precipitation totaled 5 mm.

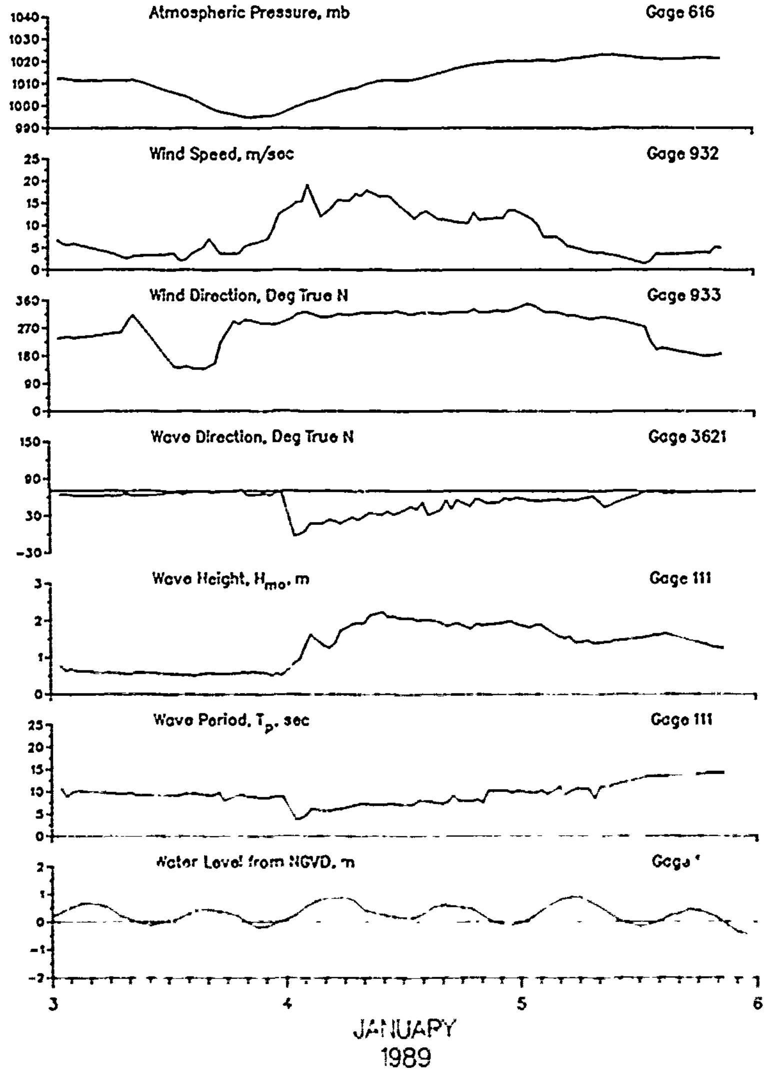


Figure 27. Data for 4 January 1989 storm

23-24 January 1989 (Figure 28)

66. On 20 January, this storm developed in the Gulf of Mexico and slowly moved across Florida into the Atlantic early on 23 January. Blocked by a New England high pressure system, the storm was unable to move up the coast and was forced into the open ocean. Maximum wind speeds (from north) exceeding 13 m/sec were recorded on 23 January at 1334 EST. The maximum H_{mo} (Gage 111) of 3.08 m (T_p = 10.67 sec) occurred at 1600 EST. Because the storm tracked well to the south of the FRF, the atmospheric pressure remained high, dropping only to 1015.8 mb. There was no precipitation.

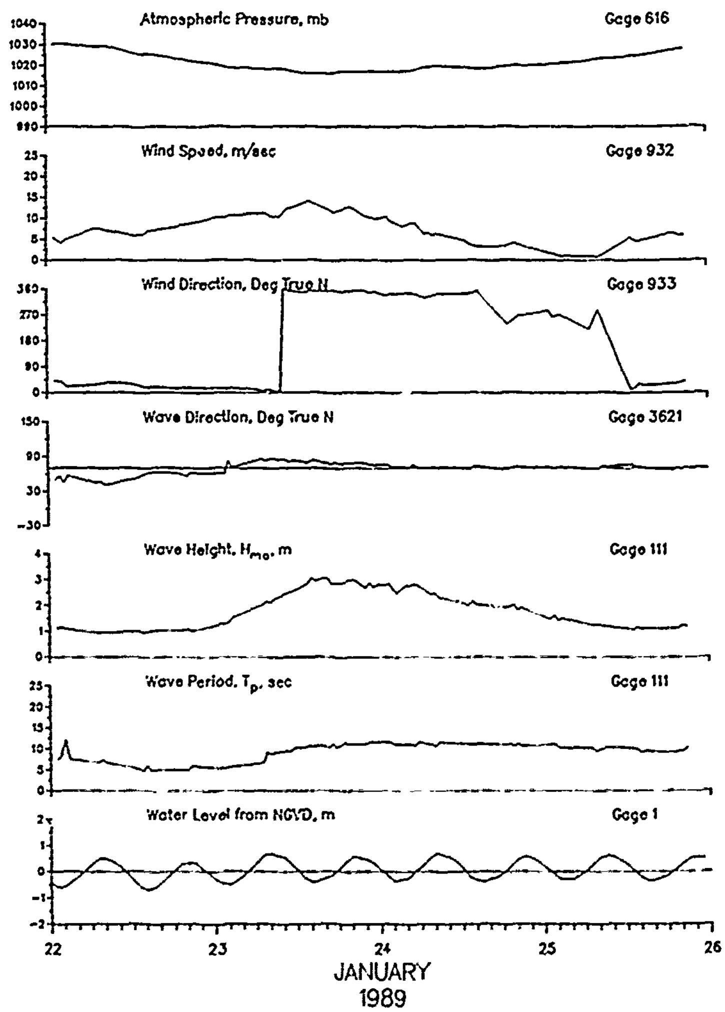


Figure 28. Data for 23-24 January 1989 storm

17-19 February 1989 (Figure 29)

67. Strong onshore winds (from northeast) generated by a Canadian high pressure system were reinforced by the formation of a storm off the North Carolina coast early on 18 February. Blocked by the high pressure system to the north, the storm quickly moved offshore. Peak winds (from northeast) exceeded 16 m/sec, coinciding with the maximum H_{mo} (Gage 625) of 2.86 (T_p = 7.53 sec). Both events were recorded on 18 February at 1634 EST. The minimum atmospheric pressure of 1,019 mb occurred on 19 February at 0242 EST. Total precipitation was 42 mm.

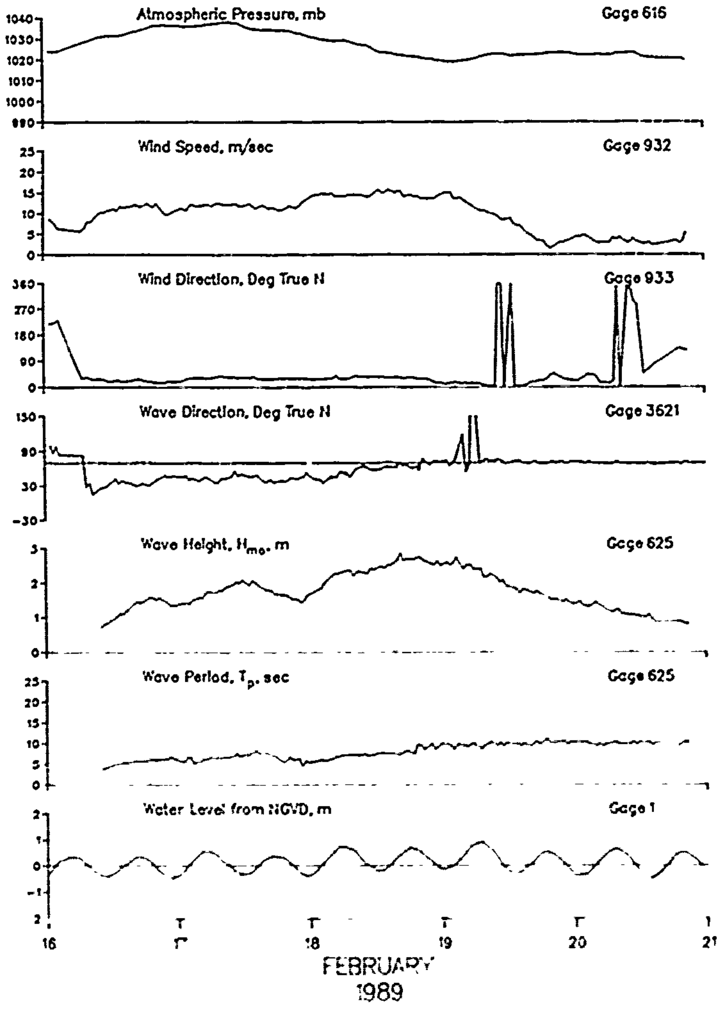


Figure 29. Data for 17-19 February 1989 storm

23-25 February 1989 (Figure 30)

68. This powerful northeaster developed off the North Carolina coast on 23 February and rapidly intensified. On 24 February, the storm picked up speed as it moved up the coast and was located off the New England coast by 25 February. Onshore winds (from north) approached 20 m/sec at 0434 EST on 24 February followed by the maximum H_{mo} (Gage 625) of 4.09 m (T_p = 11.13 sec) at 1000 EST. The minimum atmospheric pressure of 1,006.1 mb was recorded the same day at 0242 EST. Total precipitation was 12 mm. A number of cottages and motels along the Outer Banks were damaged by this storm, and erosion was severe to much of the oceanfront dune system, resulting in scarps up to 7 m in height.

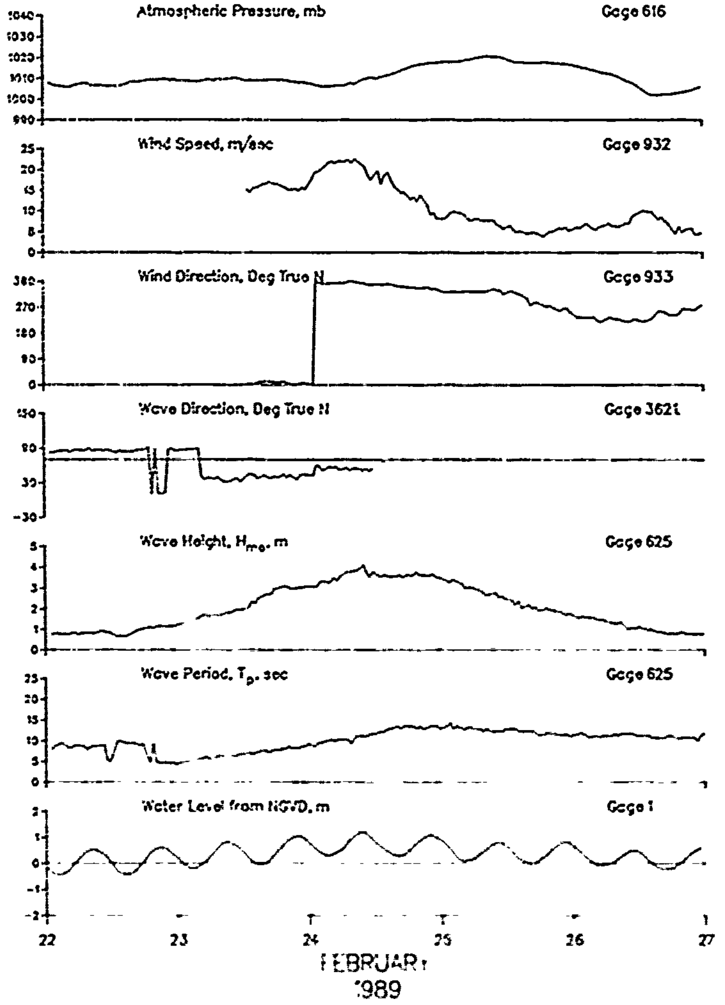


Figure 30. Data for 23-25 February 1989 storm

7-11 March 1989 (Figure 31)

69. Forming over Alabama early on 6 March this complex storm moved off the North Carolina coast on 7 March and promply stalled. Forming on a stationary front over the Florida Keys, a secondary low pressure system quickly intensified as it crossed Florida and moved into the Atlantic. Blocked by a Canadian high pressure system, the storm slowly moved up the coast, finally stalling off the Georgia coast, changed direction, and moved offshore. By 11 March the storm no longer threatened the coastline. Maximum wind speeds (from north-northeast) approached 18 m/sec at 0242 EST on 8 March. However, onshore winds exceeding 15 m/sec lasted for 59 consecutive hours. The maximum H_{mo} (Gage 111) of 4.23 m (T_p = 12.19 sec) occurred at 1934 EST on 7 March. The minimum atmospheric pressure of 1,007.3 mb (this pressure reading indicates that the storm's center was never close to the FRF) was recorded on 6 March at 1442 EST. Precipitation totaled 28 mm.

70. This storm destroyed or damaged over 100 cottages and motels along the Outer Banks and as such was the most destructive storm in this area since the infamous "Ash Wednesday" (March 1962) storm. In addition to the storm's intensity and duration, several contributing factors coincided to increase its destructive potential. These included spring tides occurring during the height of the storm and a beach already severely eroded by intense storms in February.

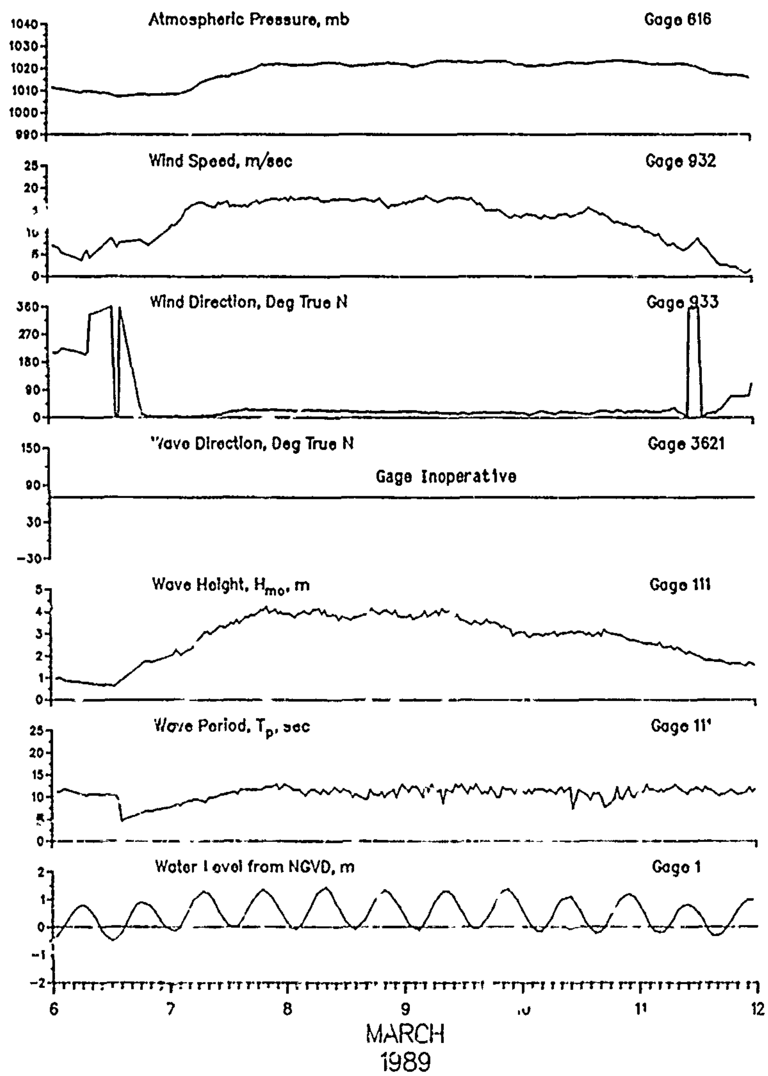


Figure 31. Data for 7-11 March 1989 storm

23-24 March 1989 (Figure 32)

71. Developing in the Gulf of Mexico on 23 March, this storm rapidly traveled up the eastern seaboard, arriving over eastern North Carolina early on 24 March, and reached New England the next day. Maximum wind speeds (from northeast) exceeded 14 m/sec on 23 March at 1442 EST, followed several hours later (2200 EST) by the maximum H_{mo} (Gage 625) of 2.35 m (T_p = 9.48 sec). The minimum atmospheric pressure of 1,009.6 mb was recorded on 24 March at 1142 EST. Total precipitation was 60 mm.

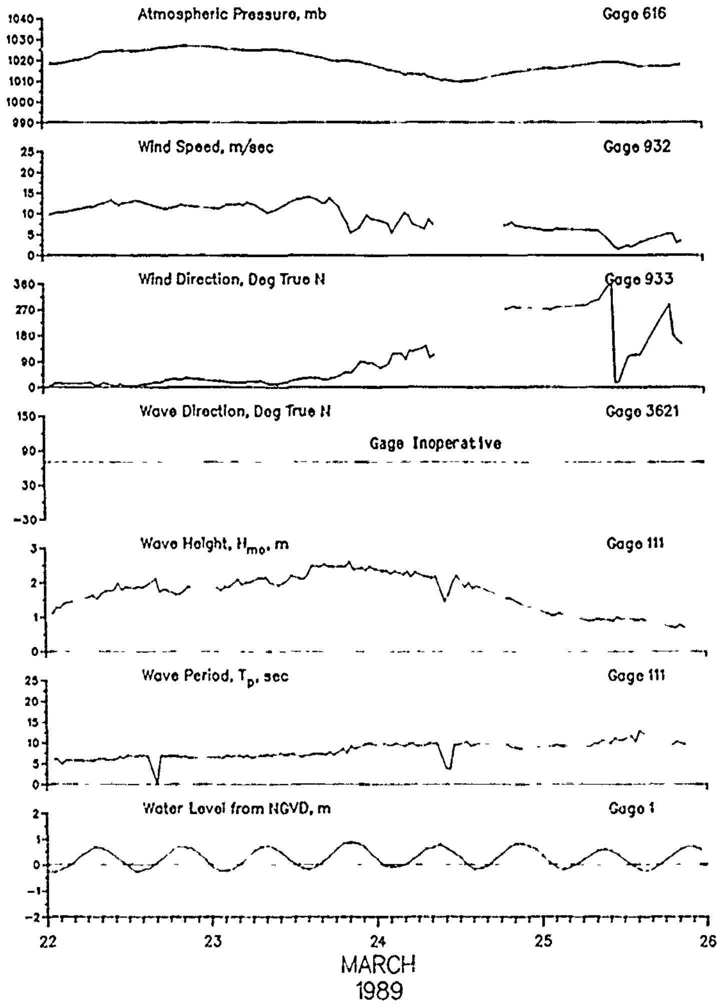


Figure 32. Data for 23-24 March 1989 storm

11 April 1989 (Figure 33)

72. Developing well off the North Carolina coast on 10 April this minor storm remained stationary throughout the day, finally disintegrating on 11 April. Maximum onshore winds (from north-northeast) exceeded 15 m/sec at 0208 EST, followed several hours later by the maximum H_{mo} (Gage 625) of 2.08 m (T_p = 6.74 sec). The atmospheric pressure only dropped to 1,018.3 mb early on 10 April. Precipitation amounted to 26 mm.

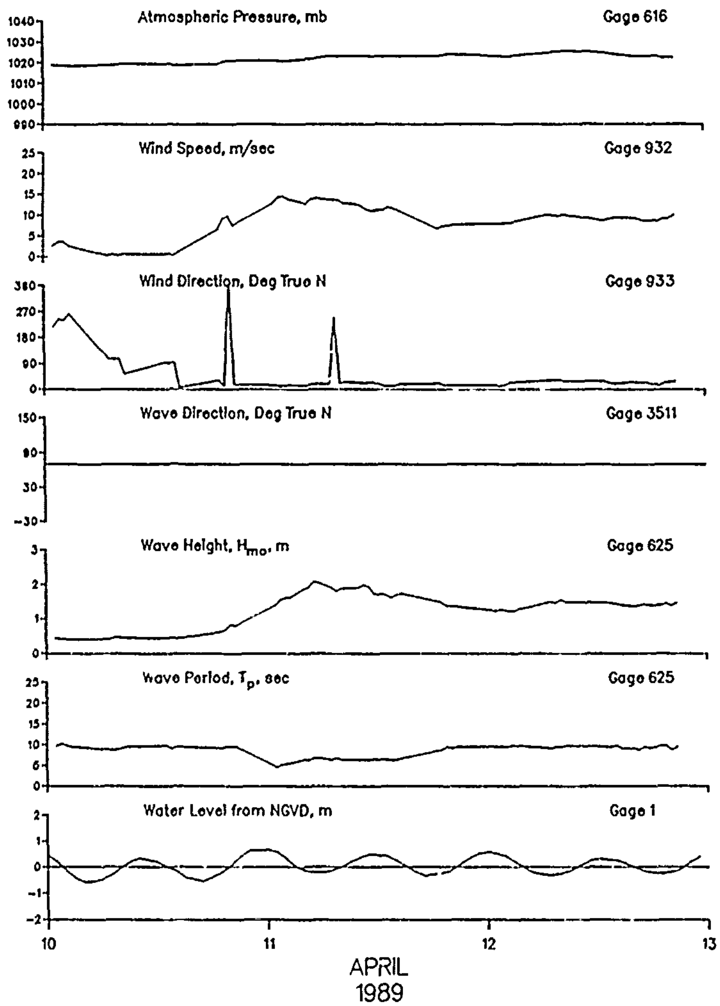


Figure 33. Data for 11 April 1989 storm

4-10 September 1989, Hurricane Gabrielle (Figure 34)

73. Storm waves, initially caused by strong (over 13 m/sec) northeast winds following the passage of a cold front on 3 September, attained an H_{mo} (at Gage 625) of 2.54 m (T_p = 9.48 sec) late on 4 September. Moderate winds through 5 September kept the H_{mo} above 2 m. Early on 6 September, with the H_{mo} hovering just above 2 m, the period took a dramatic jump to over 15 sec. This swell was generated by Hurricane Gabrielle, which remained well out to sea as it skirted the Bahamas on a northerly track that paralleled the US coast. These long period waves continued to buffet the Outer Banks through the morning of 10 September. The highest measured H_{mo} (Gage 625) of 2.54 m (Tp = 13.47 sec) was recorded at 1108 EST on 9 September. Because the hurricane remained far offshore, neither the atmospheric pressure nor the winds at the FRF were influenced by the storm.

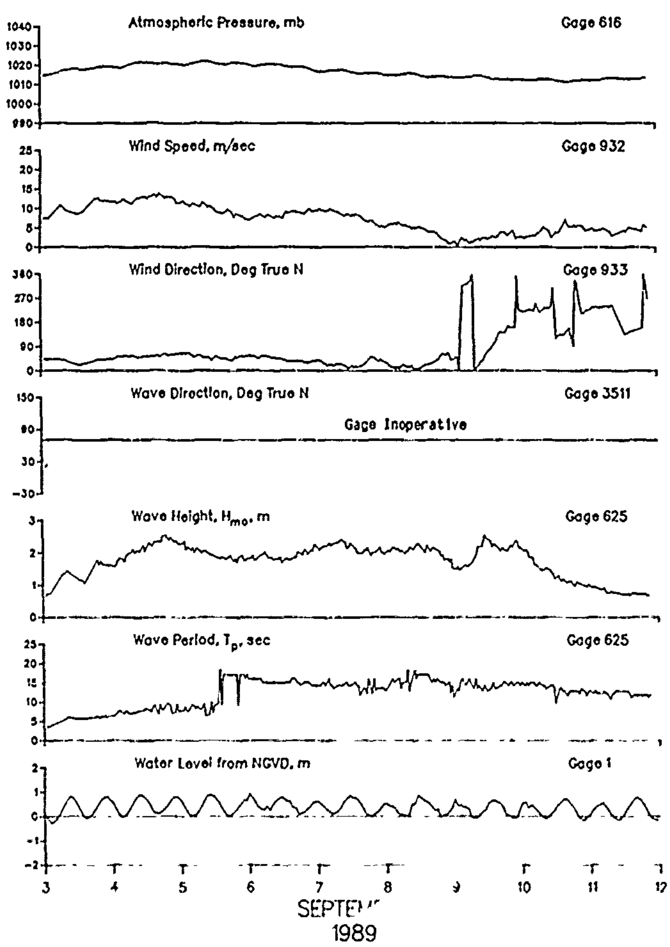


Figure 34. Data for 4-10 September 1989 storm

21-22 September 1989, Hurricane Hugo (Figure 35)

74. Hurricane Hugo made landfall at approximately 2200 EST on 21 September near the city of Charleston, SC, causing tremendous damage to the beaches and coastal towns of South Carolina. Other communities far from the coast were also damaged as the storm traveled well inland before turning north. The FRF, which is approximately 565 km north of Charleston, received only minimal effects from Hugo as the storm's inland path was well west of the area. Waves with H_{mo} exceeding 2 m began arriving at the FRF early on 21 September with the highest H_{mo} (Gage 625) of 2.50 m (T_p = 15.06 sec) recorded several hours later at 1408 EST. Maximum onshore (from the northeast) winds exceeded 12 m/sec late on 21 September. Due to the storm's distance, the atmospheric pressure dropped only to 1,011.4 mb early on 22 September. There was no precipitation at the FRF.

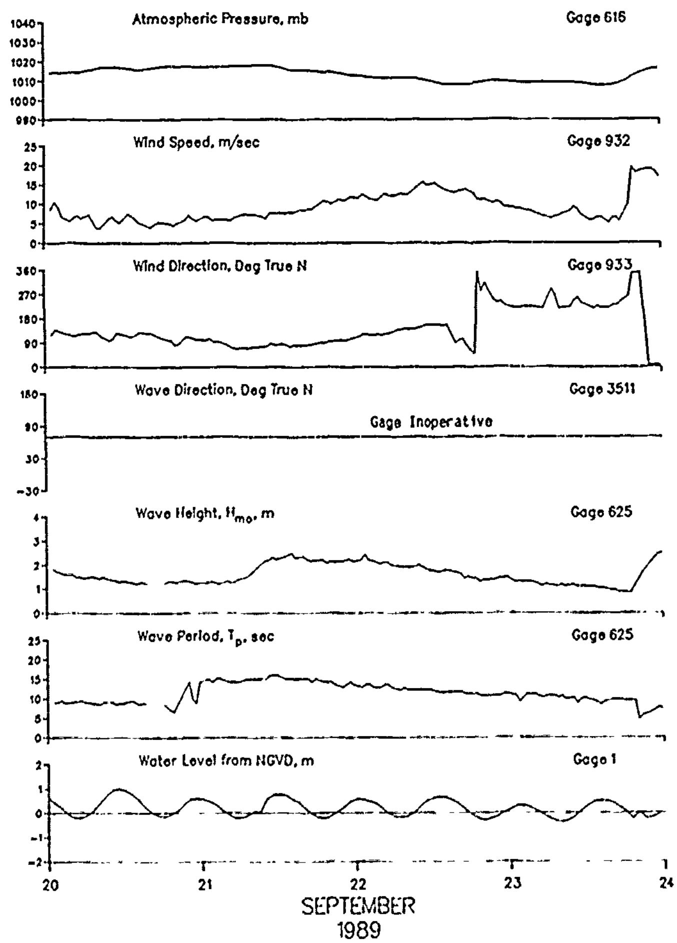


Figure 35. Data for 21-22 September 1989 storm

23-24 September 1989 (Figure 36)

75. Following the passage of a cold front, strong winds generated by a large high pressure system located over Michigan began to affect the FRF late on 23 September. Maximum wind speeds (from the north-northeast) exceeding 18 m/sec occurred on 23 September at 2200 EST. The maximum H_{mo} (Gage 625) of 2.50 m (T_p = 7.53 sec) was recorded 2 hr later at 2342 EST. Total precipitation was 6 mm.

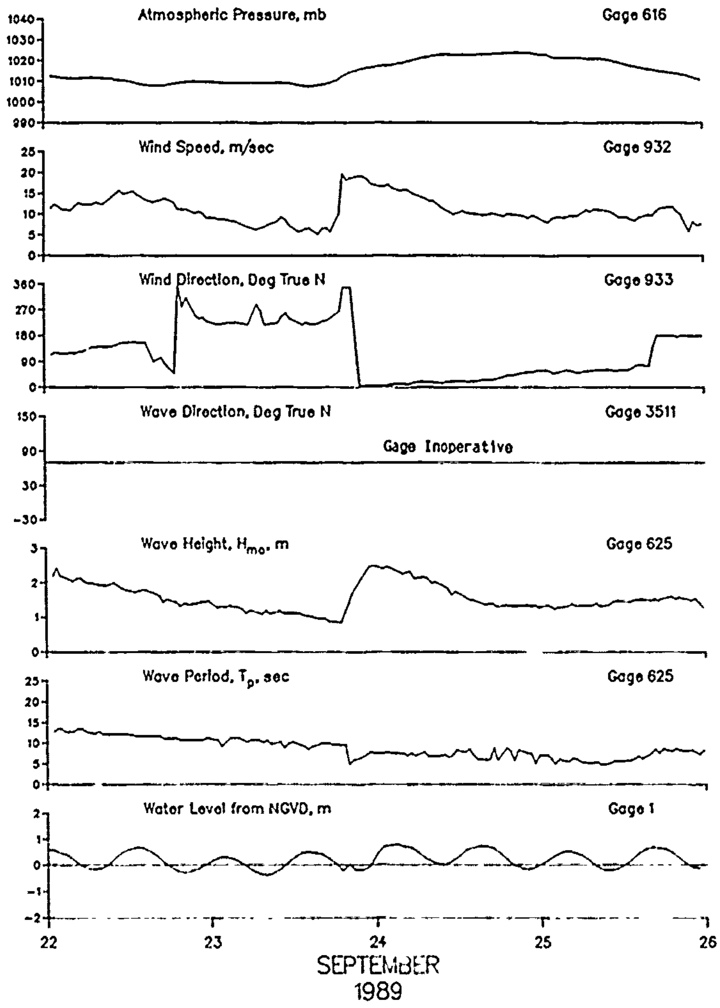


Figure 36. Data for 23-24 September 1989 storm

27 September 1989 (Figure 37)

76. Forming off the Georgia coast early on 25 September, this "northeaster" quickly moved up the coast reaching the Maryland shore on 26 September. Peak winds (from the north) exceeded 15 m/sec on 27 September at 0434 EST. The maximum H_{mo} (at Gage 625) of 2.39 m (T_p = 7.76 sec) occurred 4 hr later at 0842 EST. The minimum atmospheric pressure of 1,008.6 mb was recorded on 26 September at 0400 EST. Total precipitation was 54 mm.

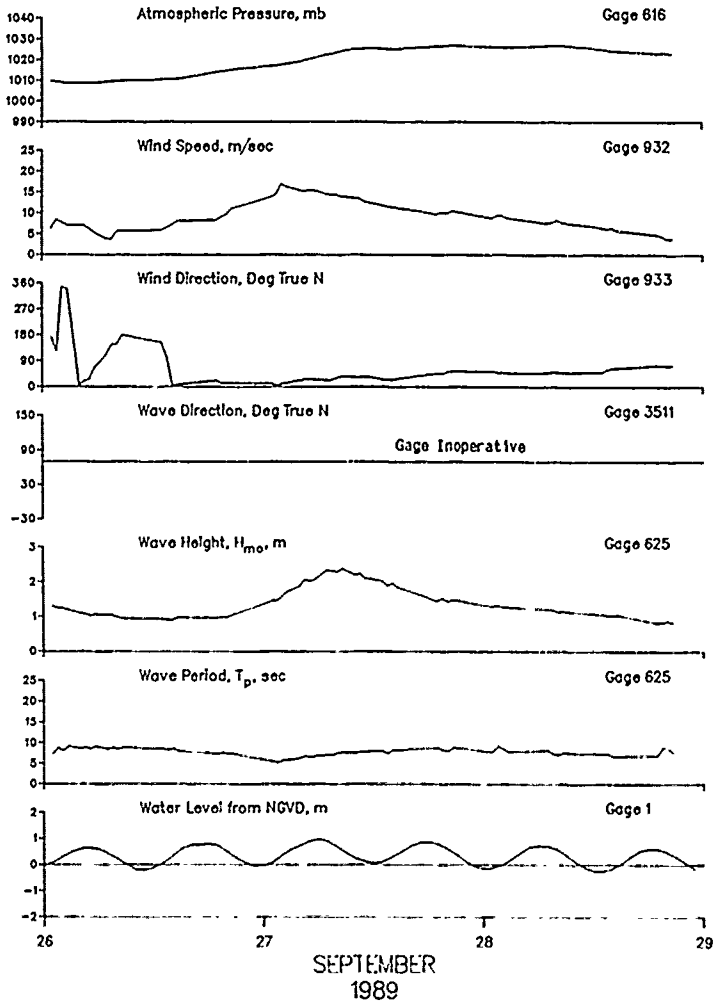


Figure 37. Data for 27 September 1989 storm

25-26 October 1989 (Figure 38)

77. A strong high pressure system stalled over West Virginia generated winds (from north-northeast) that produced storm waves for 2 days at the FRF. Peak winds of 13 m/sec were recorded early on 24 October with the maximum H_{mo} (Gage 625) of 2.60 m (T_p = 12.19 sec) occurring at 2008 EST on 25 October.

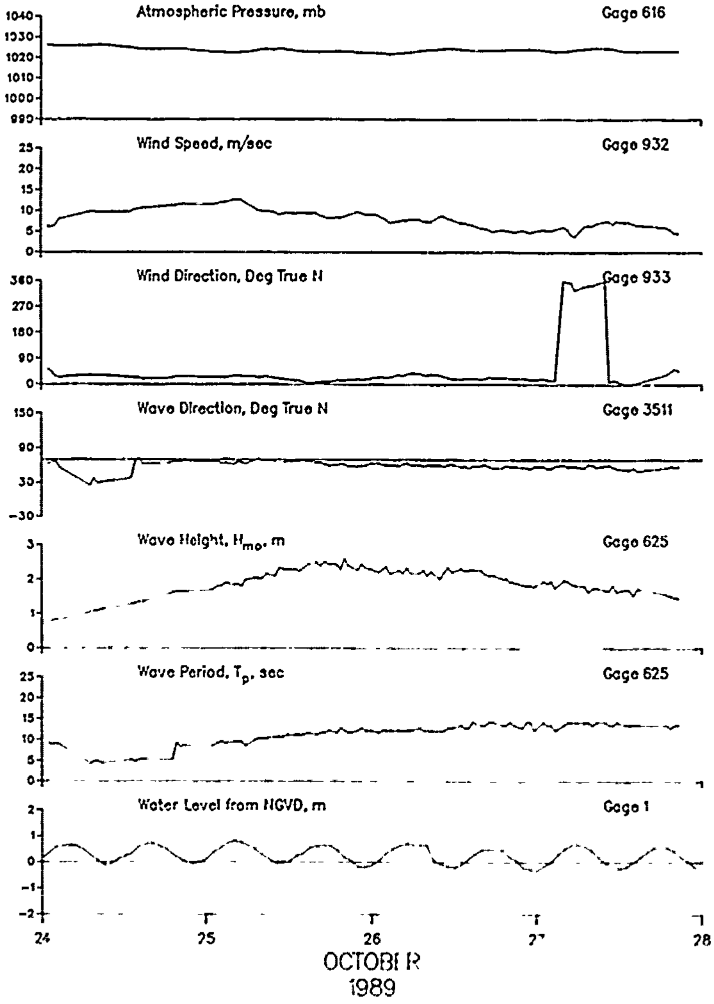


Figure 38. Data for 25-26 October 1989 storm

23 November 1989 (Figure 39)

78. Developing over Texas early on 22 November, this storm quickly moved to the east, being located off North Carolina on 23 November. Maximum wind speeds (from north-northeast) exceeded 19 m/sec at 0542 EST, on 23 November. Recorded several hours later at 0808 EST, the peak H_{mo} (T_p = 6.92 sec) reached 2.32 m (Gage 625). The minimum atmospheric pressure of 1,000.7 mb occurred at 0134 EST, also on 23 November. Total precipitation was 39 mm.

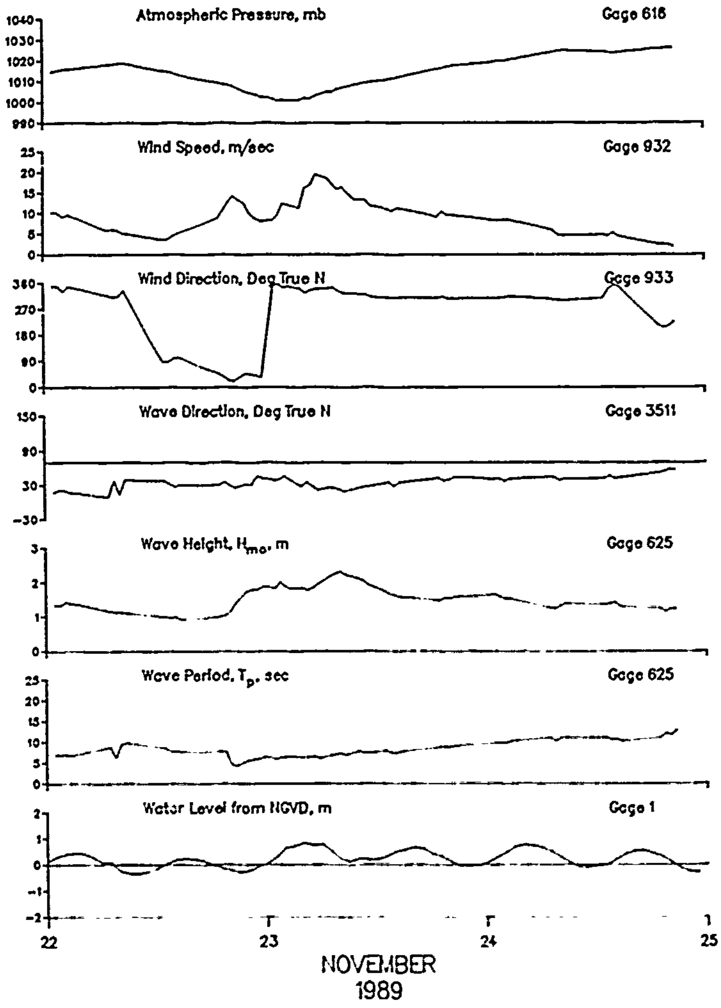


Figure 39. Data for 23 November 1989 storm

8-10 December 1989 (Figure 40)

79. Developing over Alabama early on 8 December, this storm quickly moved to the east, being located off North Carolina on 9 December. Maximum wind speeds (from northeast) exceeded 20 m/sec at 2200 EST on 9 December. Earlier in the day at 0208 EST, the peak H_{mo} (Gage 625) reached 3.05 m (T_p = 9.85 sec). The minimum atmospheric pressure of 1,001.9 mb occurred at 2200 EST, also on 9 December. Total precipitation was 56 mm.

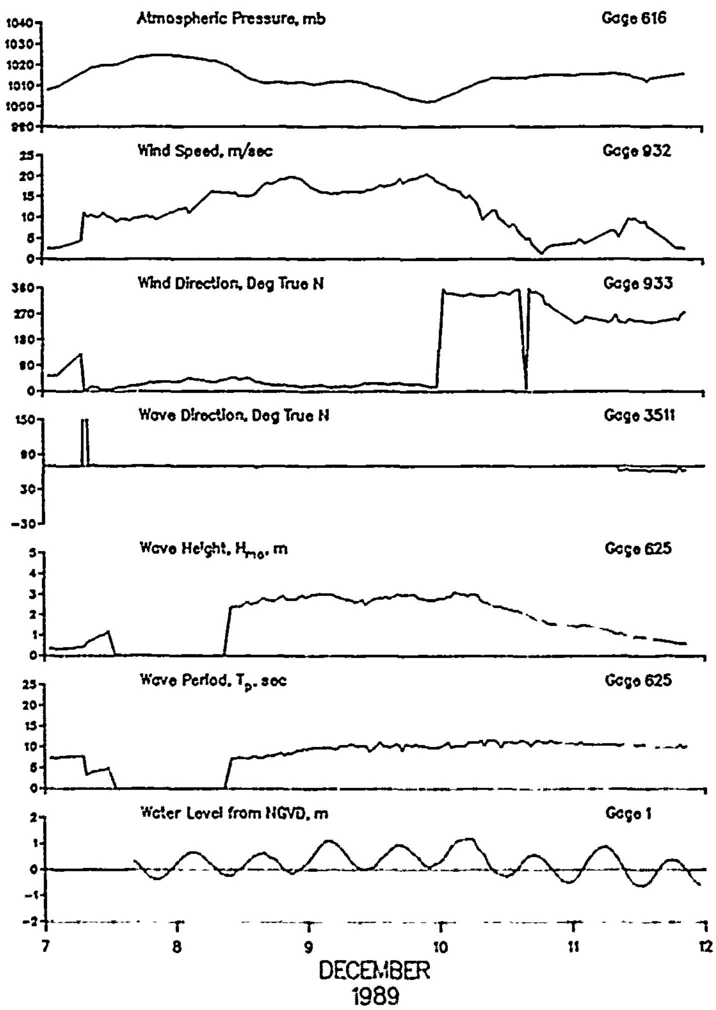


Figure 40. Data for 8-10 December 1989 storm

13 December 1989 (Figure 41)

80. Developing in the Gulf of Mexico, this small coastal storm rapidly moved into the Atlantic, being located off Cape Hatteras, NC, on 13 December. Recorded at 0808 EST, the peak wind speed (from north) surpassed 13 m/sec followed at 1334 EST by the maximum H_{mo} (Gage 625) of 2.46 m (T_p = 9.48 sec). The minimum atmospheric pressure of 1,002.7 mb occurred at 0400 EST. Total precipitation was 19 mm.

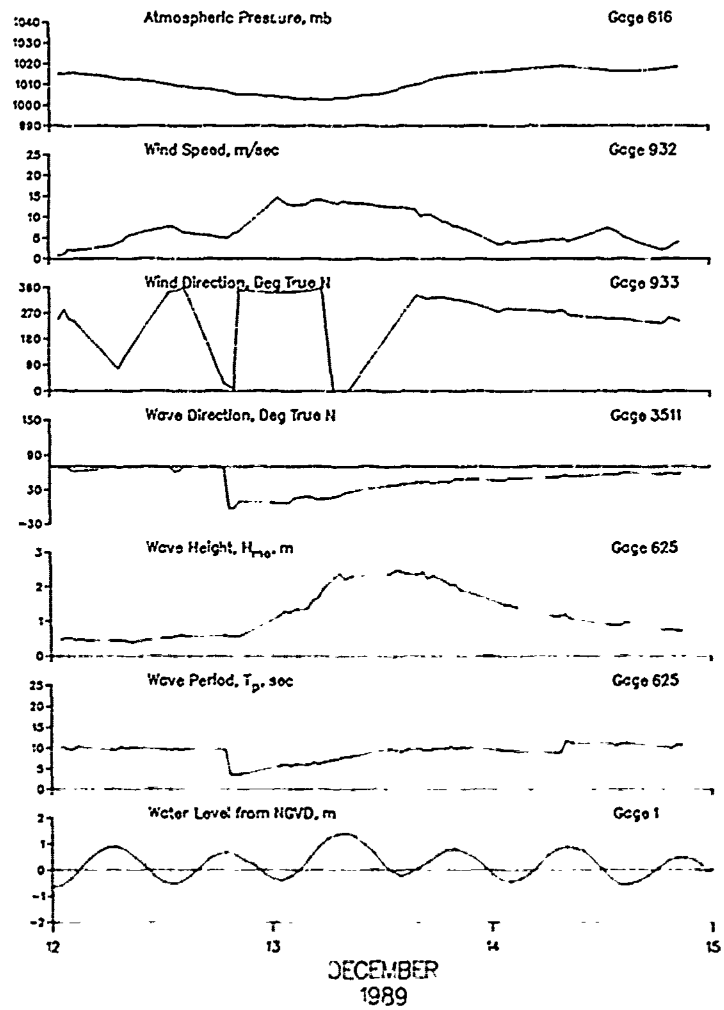


Figure 41. Data for 13 December 1989 storm

22 December 1989 (Figure 42)

81. Winds from a strong high pressure system located over the mid-western United States began to generate storm waves at the FRF early on 22 December. The maximum H_{mo} (Gage 111) of 2.31 m (T_p = 6.74 sec) was attained at 0208 EST with maximum winds (from north-northwest) of 14 m/sec occurring at 0100 EST.

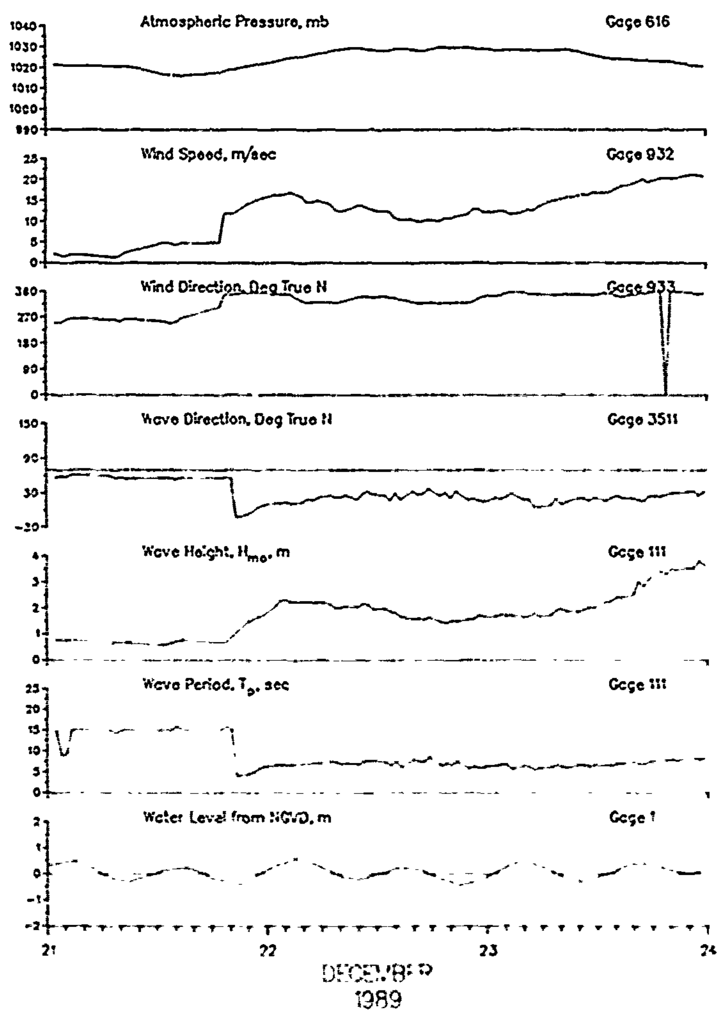


Figure 42. Data for 22 December 1989 storm

23-25 December 1989 (Figure 43)

82. Reinforced by the same mid-western high pressure system that had produced storm waves on 22 December, a storm which developed off the Georgia coast on 23 December quickly intensified into a major blizzard. The storm destroyed several previously damaged oceanfront cottages in the town of Kitty Hawk and produced gale-force winds accompanied by significant quantities of snow. The maximum H_{mo} (Gage 111) of 4.67 m (T_p = 10.67 sec) was recorded at 1442 EST on 24 December. Offshore (Gage 630), the H_{mo} reached 5.63 m (T_p = 11.13 sec) at 1300 EST the same day. Peak winds (from the north) approached 21 m/sec at 0842 EST, also on 24 December. Winds above 10 m/sec were recorded for 39 consecutive hours. Since the center of the storm remained offshore, the atmospheric pressure at the FRF dropped only to 1,012.5 mb at 1142 EST on 24 December. Due to the strong winds, the rain gages failed to collect much of the snowfall. Approximately 20 to 25 cm of snow fell at the FRF with up to 36 cm reported at other locations.

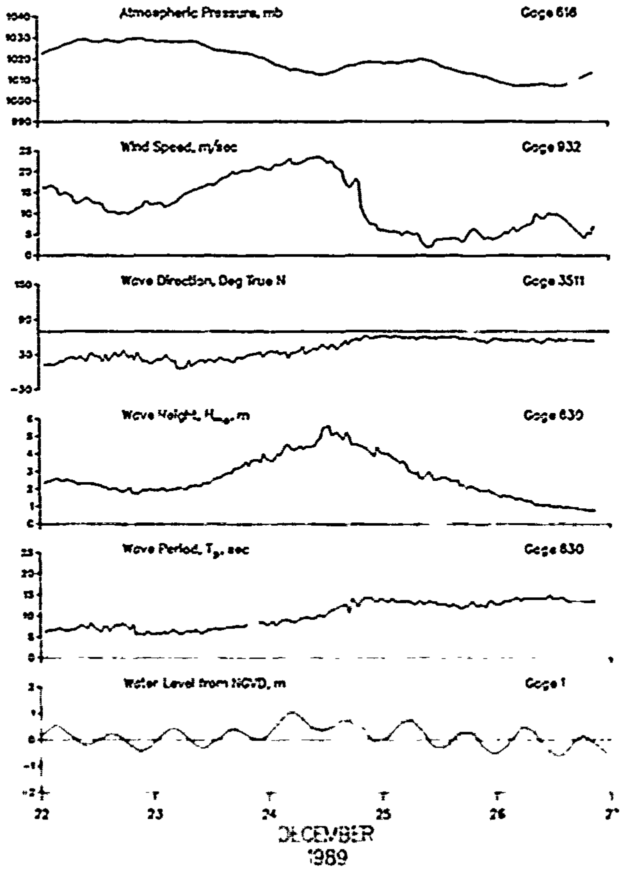


Figure 43 Data for 23-25 December 1989 storm

REFERENCES

Bingham, C., Godfrey, M. D., and Tukey, J. W. 1967. "Modern Techniques of Power Spectrum Estimation," IEEE Trans. Audio Electroacoustics, AU-15, pp 56-66.

Birkemeier, W. A., and Mason, C. 1984. "The CRAB: A Unique Nearshore Surveying Vehicle," Journal of Surveying Engineering, American Society of Civil Engineers, Vol 110, No. 1.

Field Research Facility. 1989 (Jan-Dec). "Preliminary Data Summary," Monthly Series, Coastal Engineering Research Center, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Grogg, W. E., Jr. 1986. "Calibration and Stability Characteristics of the Baylor Staff Wave Gage," Miscellaneous Paper CERC-86-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, H. C. 1980. "Instrumentation at CERC's Field Research Facility, Duck, North Carolina," CERC Miscellaneous Report 80-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, H. C., Birkemeier, W. A., and DeWall, A. E. 1983. "Effect of the CERC Research Pier on Nearshore Processes," Coastal Structures '83, American Society of Civil Engineers, Arlington, VA, pp 769-785.

US Department of Commerce. 1987. "Daily Weather Maps," Weekly Series, Washington, DC.

Welch, P. D. 1967. "The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short Modified Periodograms," IEEE Trans. Audio Electroacoustics, AE-15, pp 70-73.

APPENDIX A: SURVEY DATA

1. Contour diagrams constructed from the bathymetric survey data are presented in this appendix. The profile lines surveyed are identified on each diagram. Contours are in half meters referenced to National Geodetic Vertical Datum (NGVD). The distance offshore is referenced to the Field Research Facility (FRF) monumentation baseline behind the dune.

2. Change in FRF bathymetry diagrams constructed by contouring the difference between two contour diagrams are also presented with contour intervals of 0.25 m. Wide contour lines show areas of erosion. Other areas correspond to areas of accretion. Although these change diagrams are based on considerable interpolation of the original survey data, they do facilitate comparison of the contour diagrams.

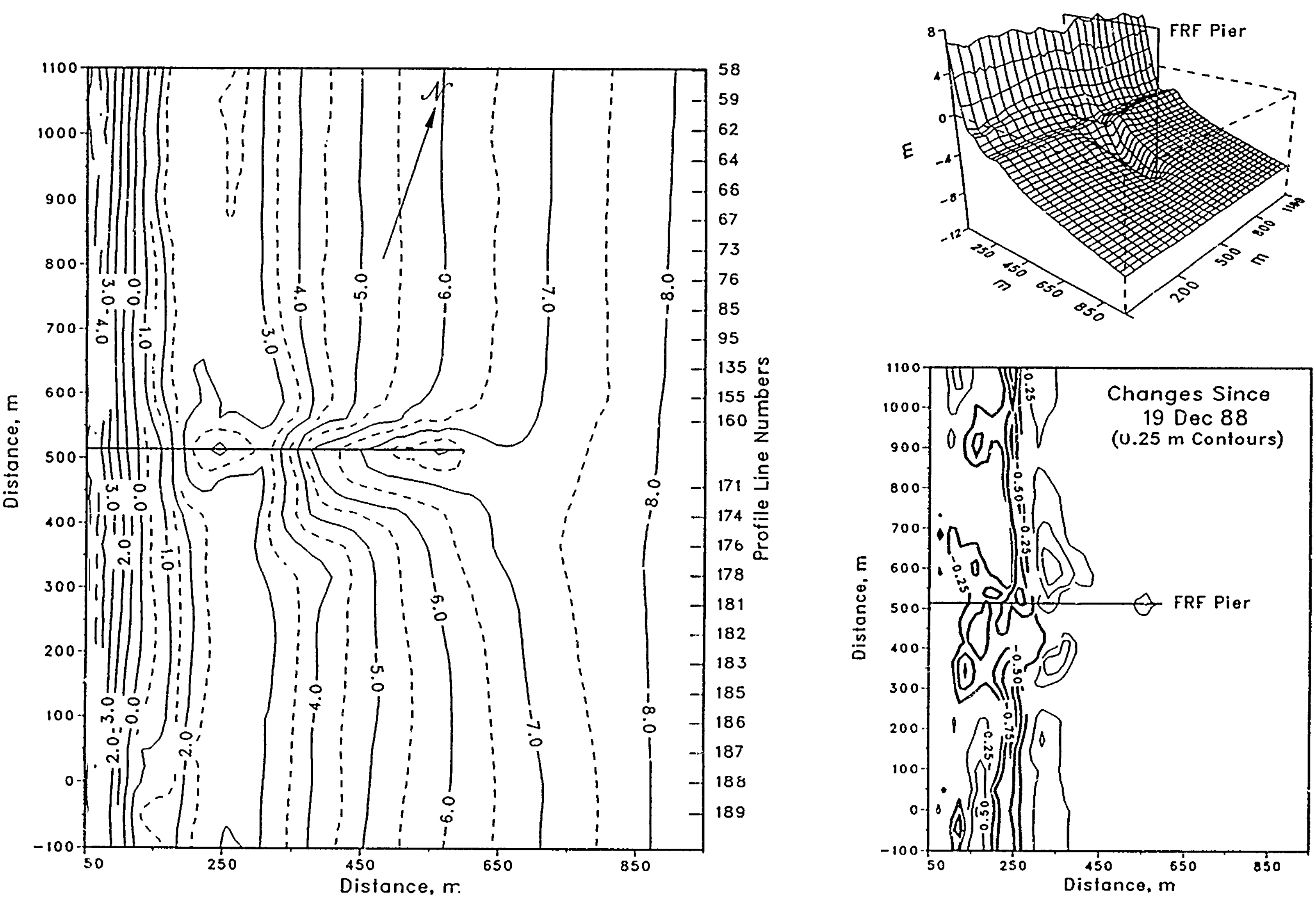


Figure A1. FRF Bathymetry 25 January 89 (depths relative to NGVD)

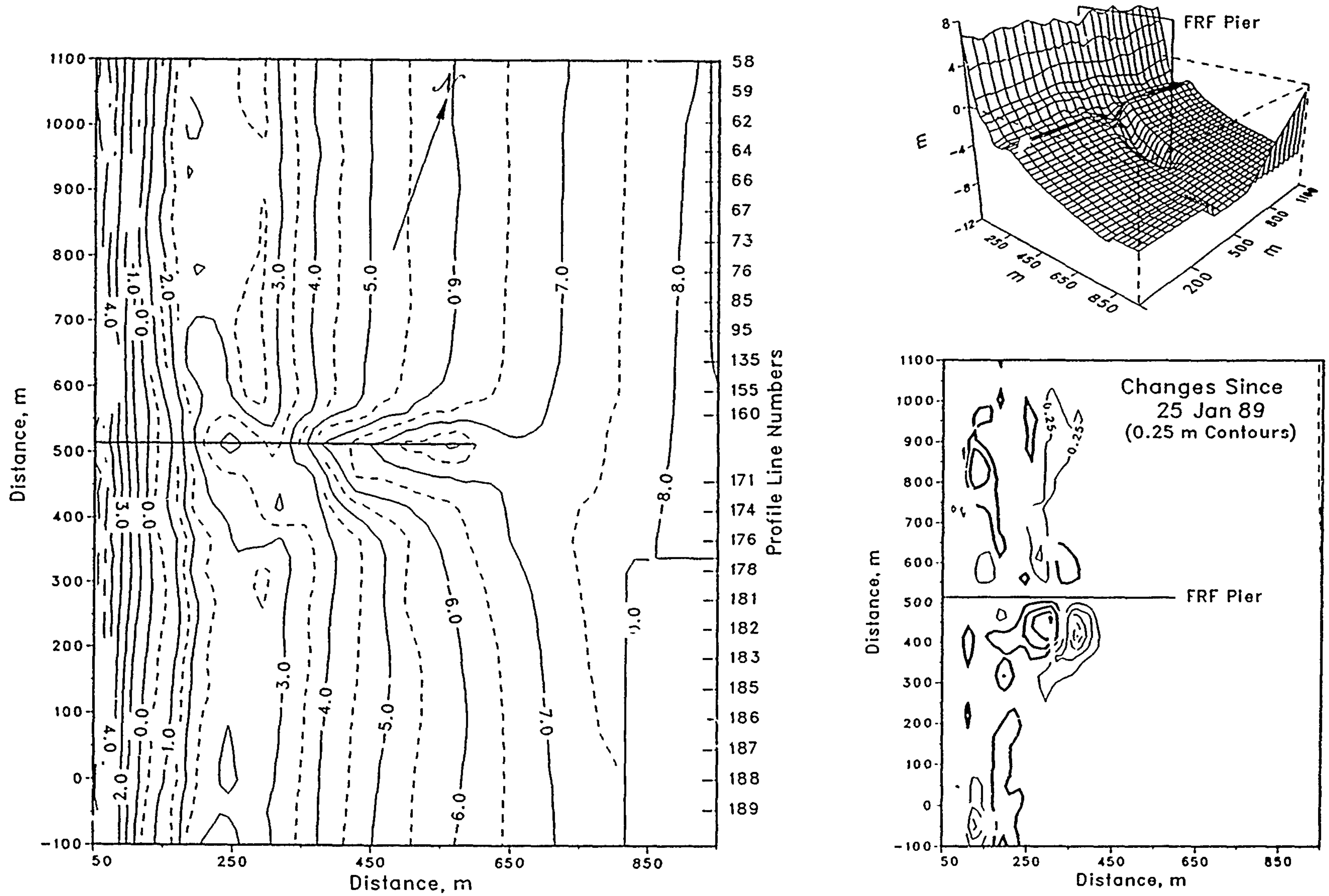


Figure A2. FRF Bathymetry 21 February 89 (depths relative to NGVD)

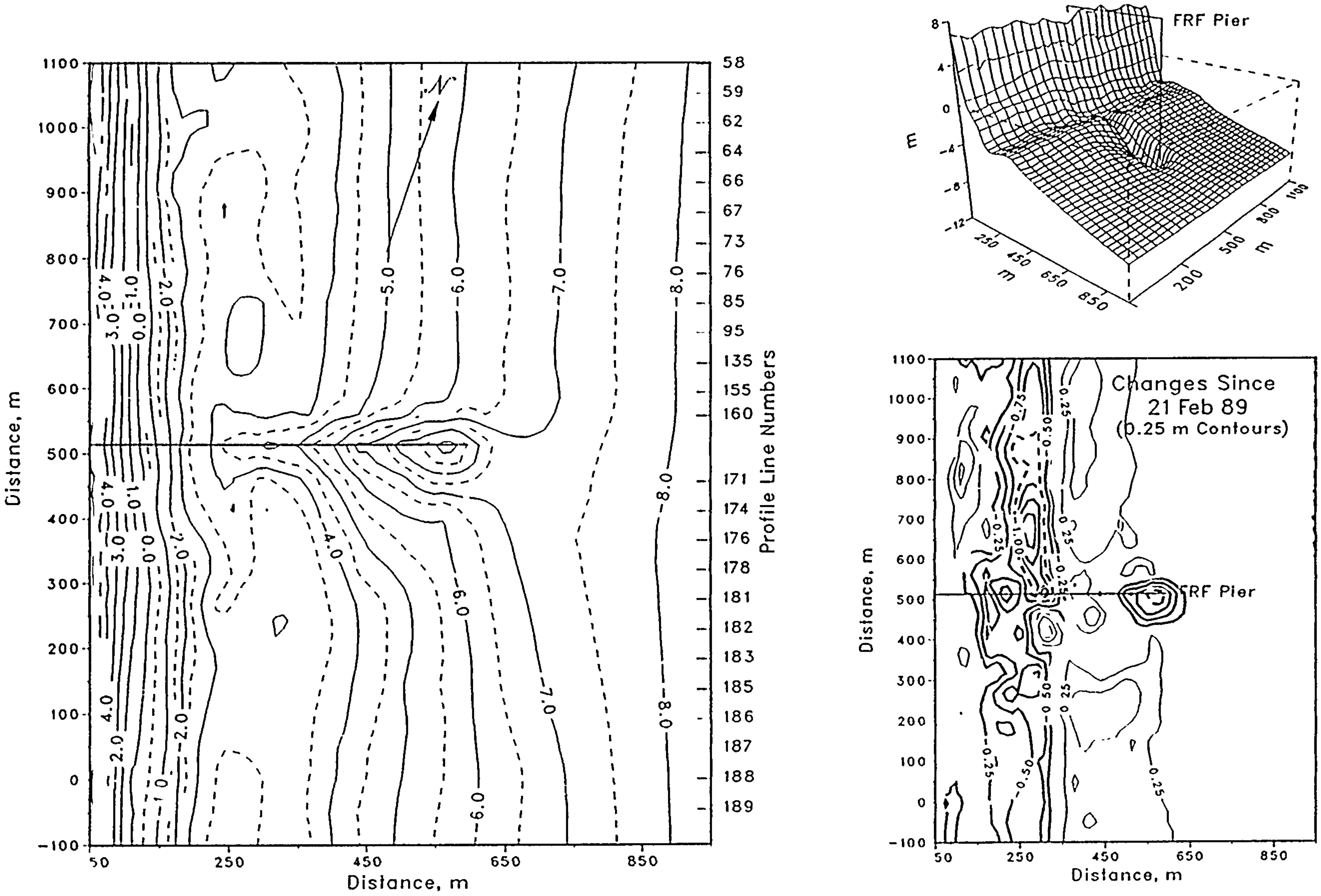


Figure A3. FRF Bathymetry 27 February 89 (depths relative to NGVD)

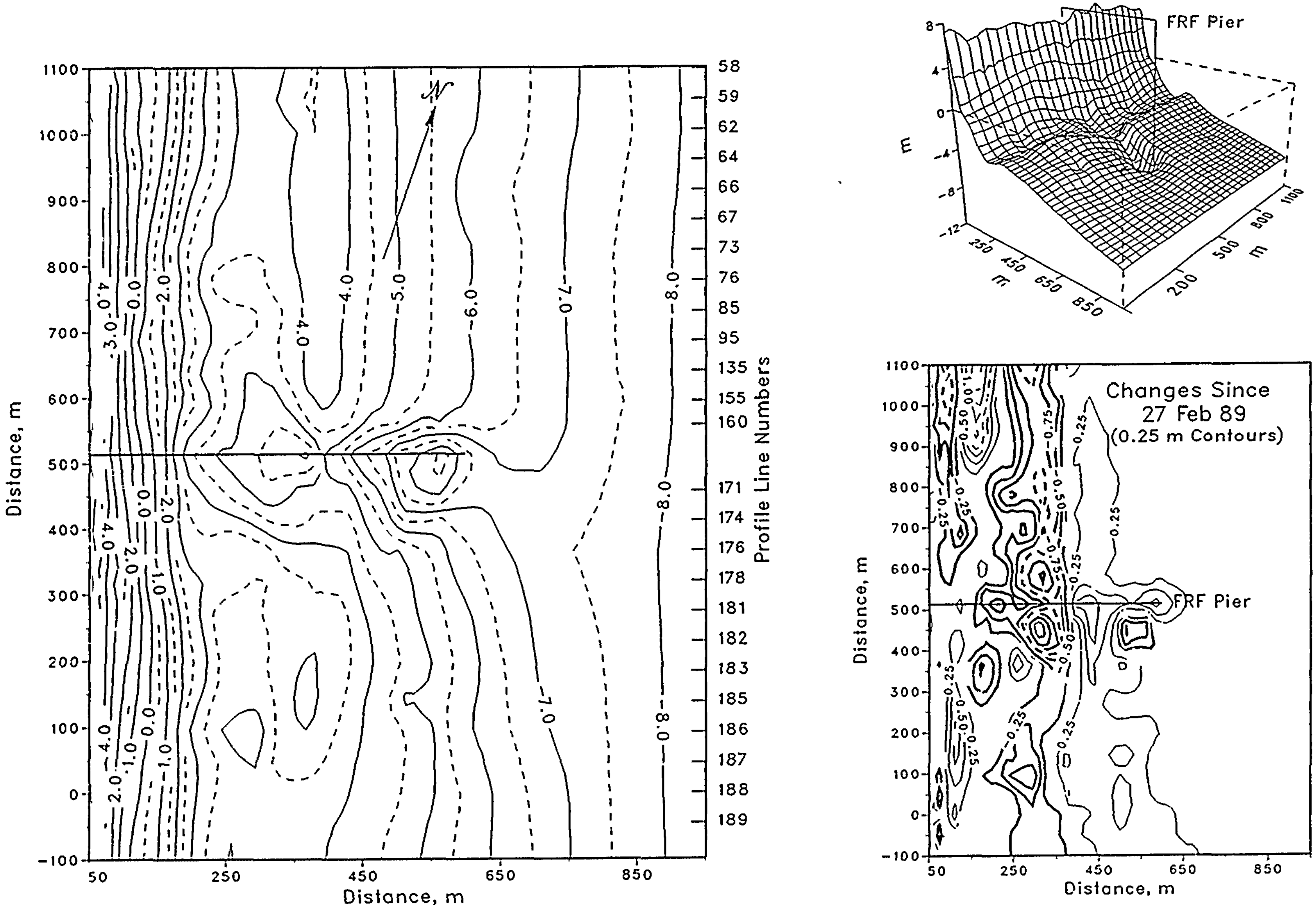


Figure A4. FRF Bathymetry 12 March 89 (depths relative to NGVD)

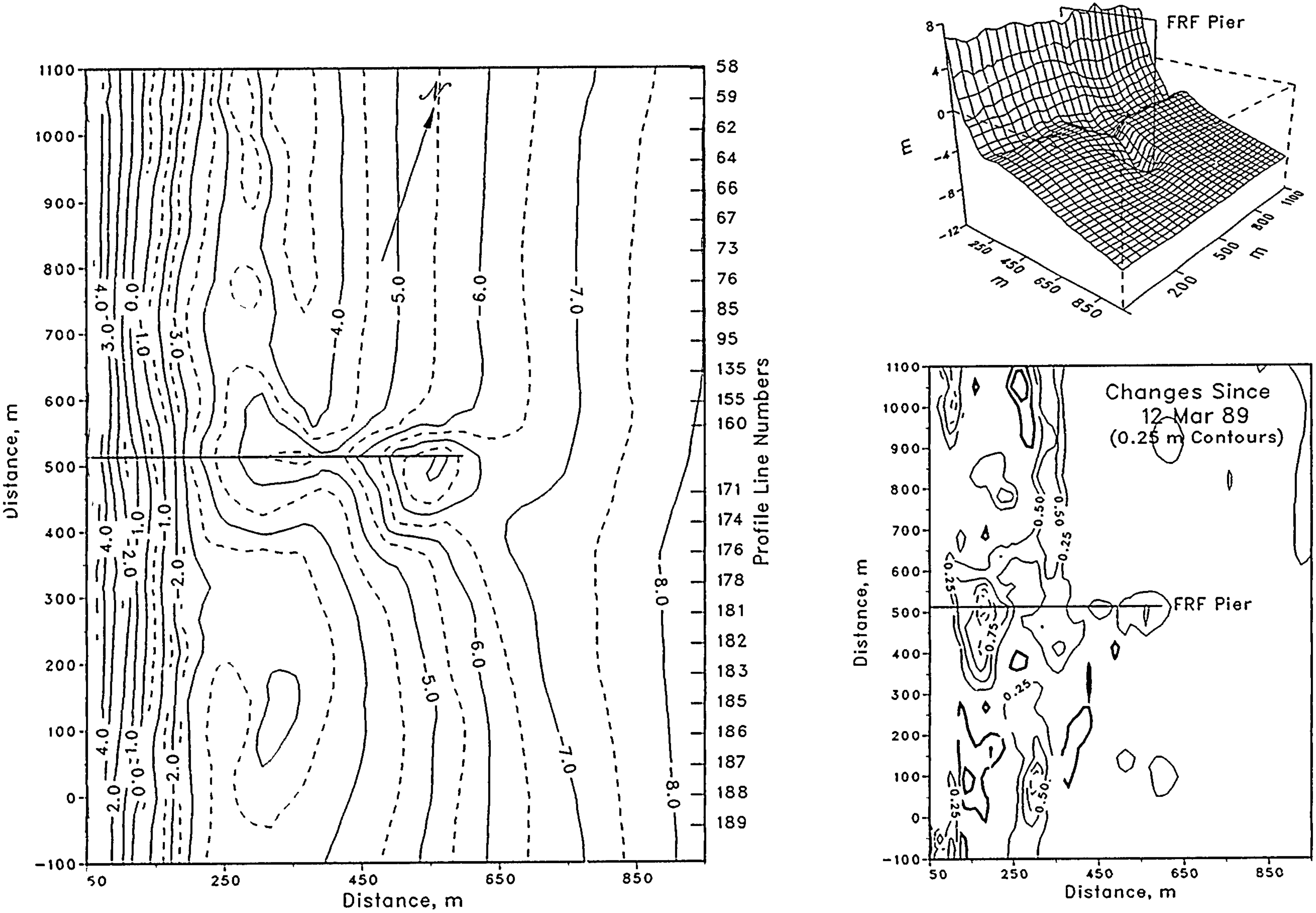


Figure A5. FRF Bathymetry 26 April 89 (depths relative to NGVD)

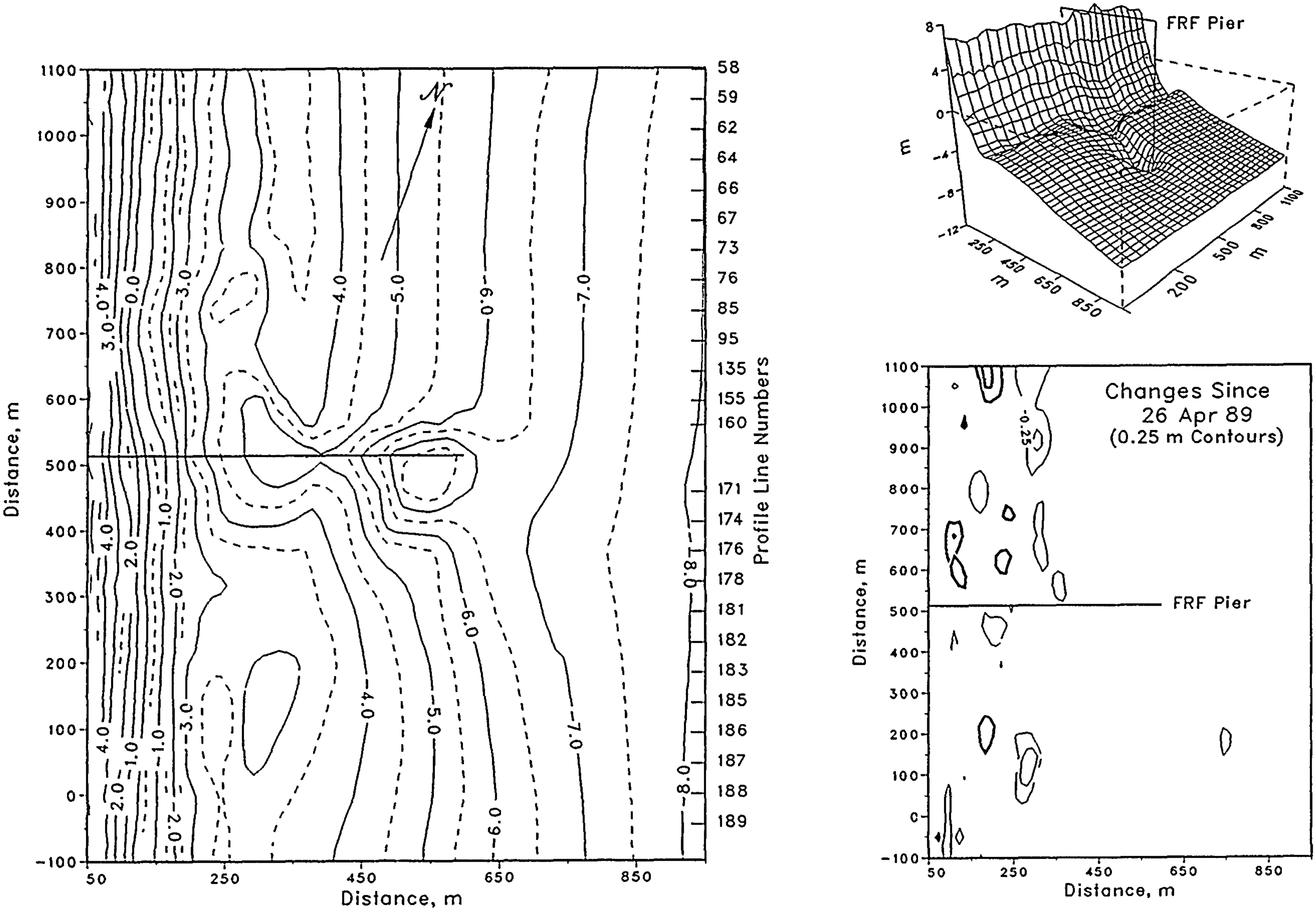


Figure A6. FRF Bathymetry 24 May 89 (depths relative to NGVD)

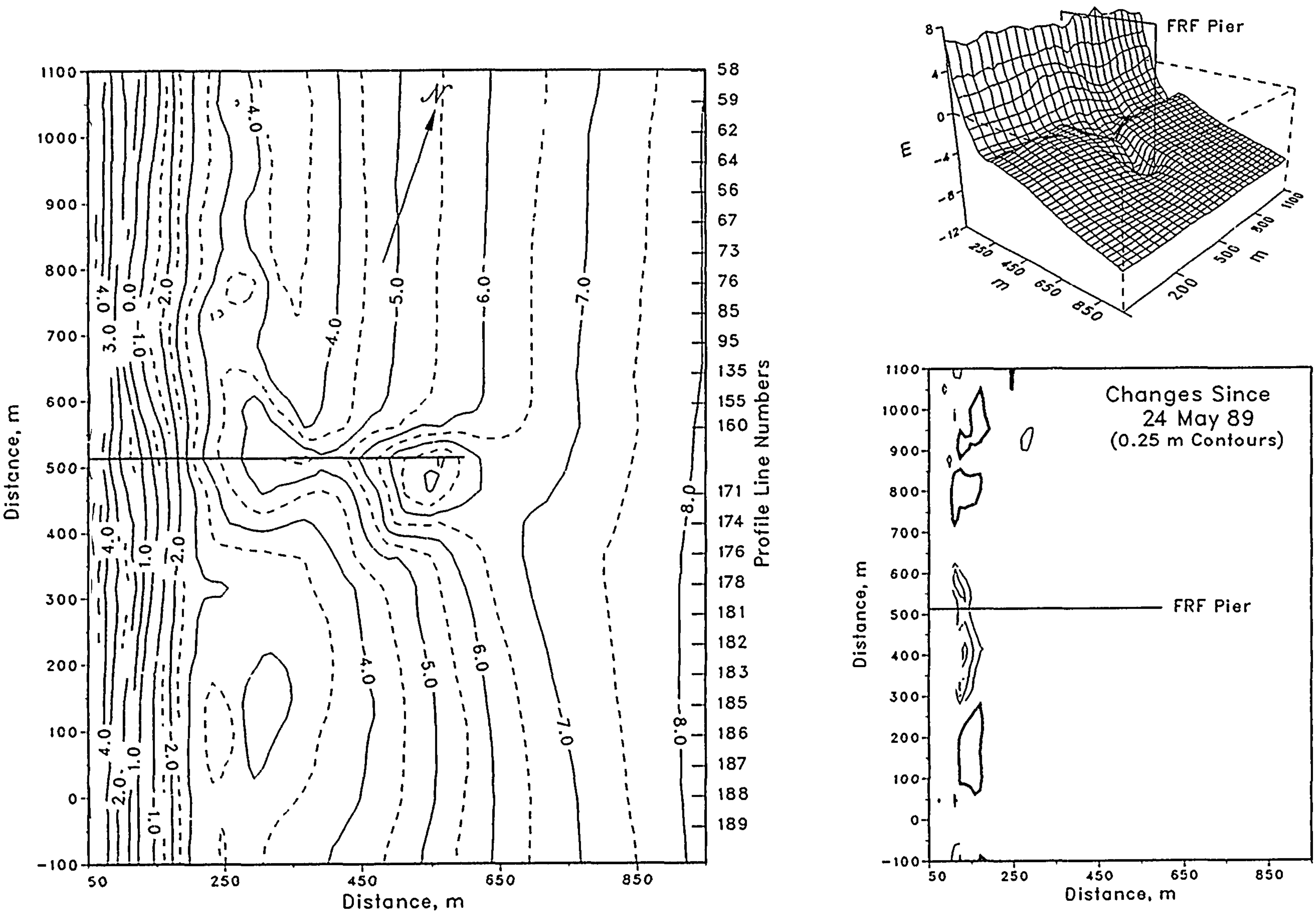


Figure A7. FRF Bathymetry 15 June 89 (depths relative to NGVD)

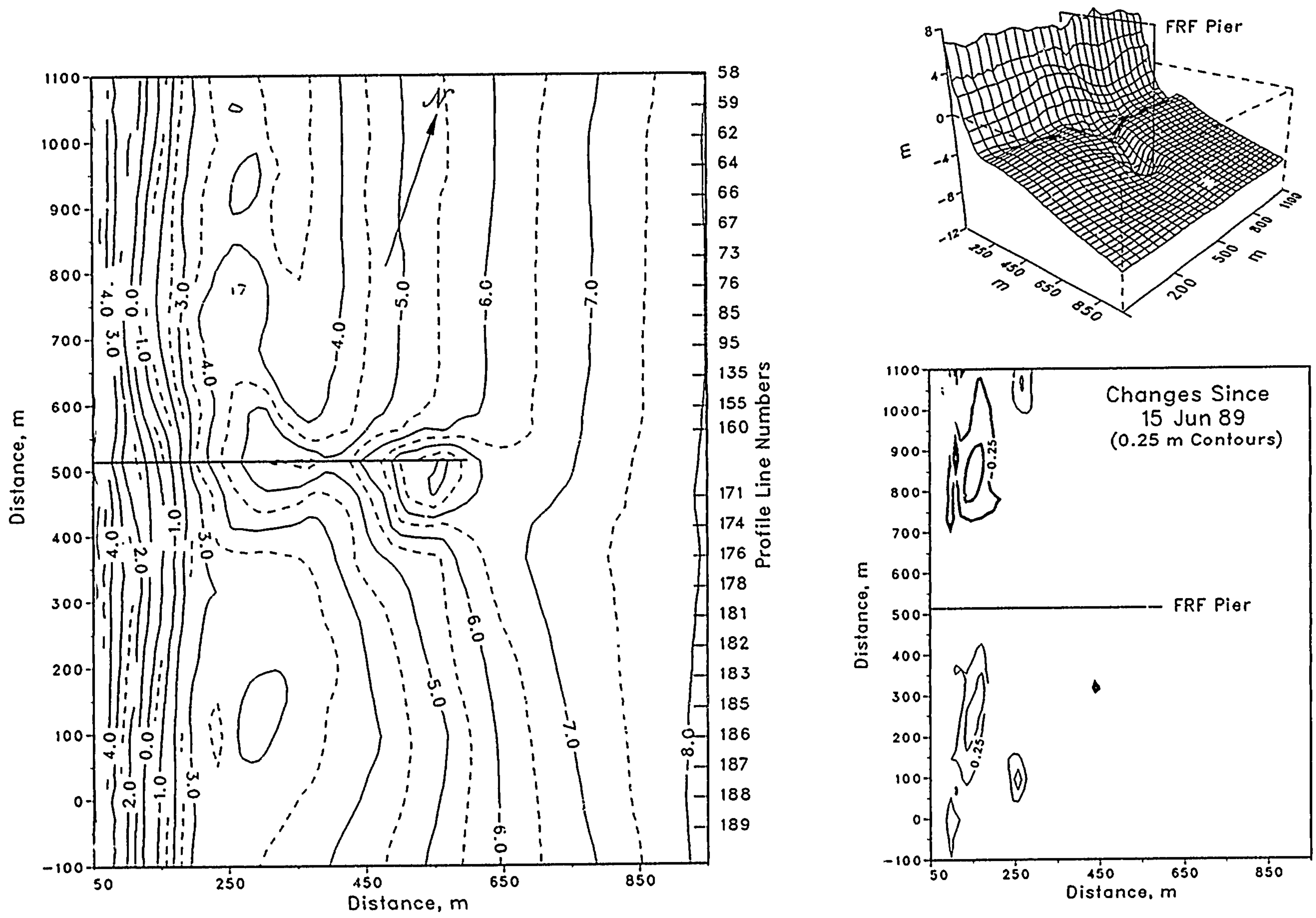


Figure A8. FRF Bathymetry 26 July 89 (depths relative to NGVD)

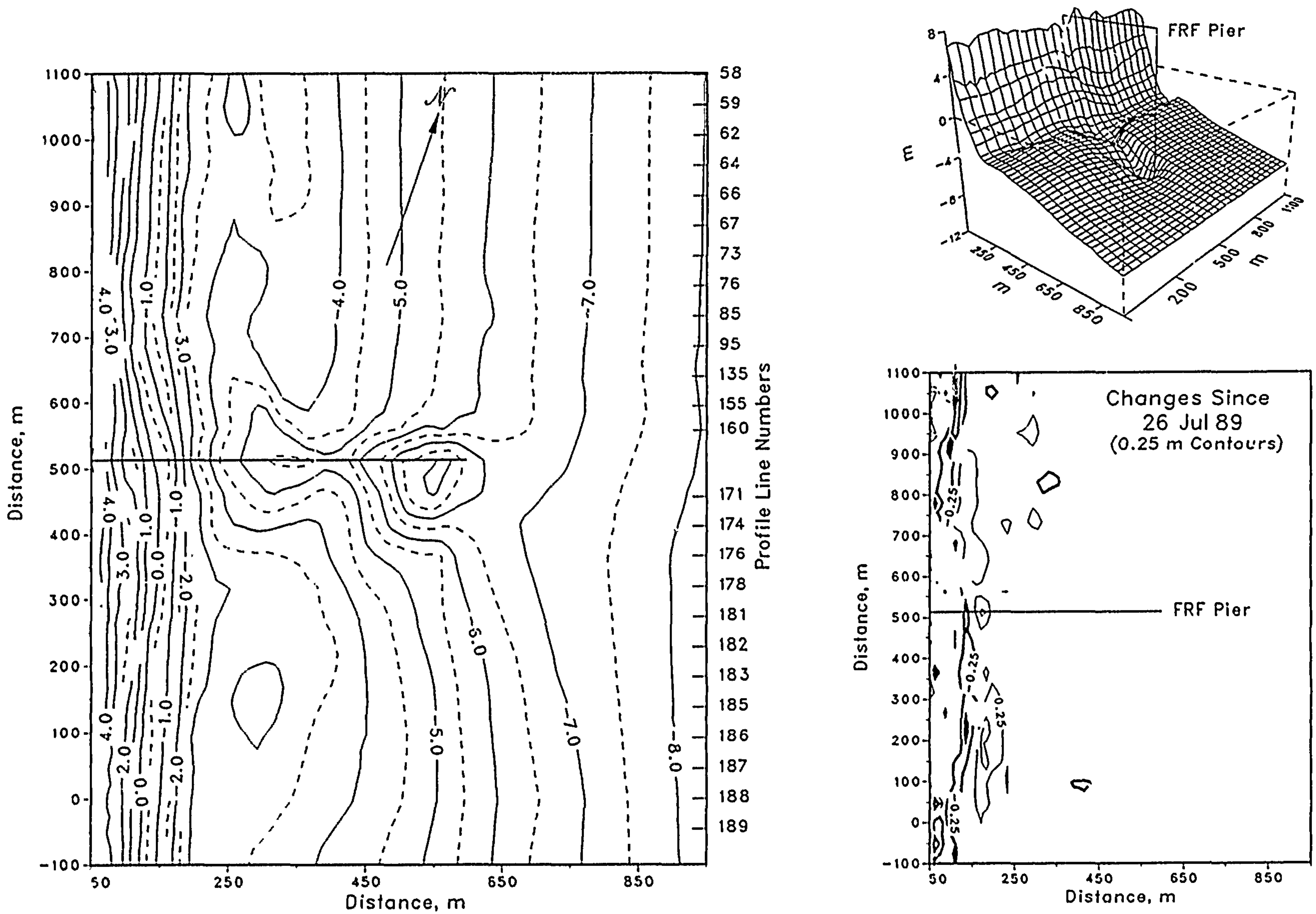


Figure A9. FRF Bathymetry 15 August 89 (depths relative to NGVD)

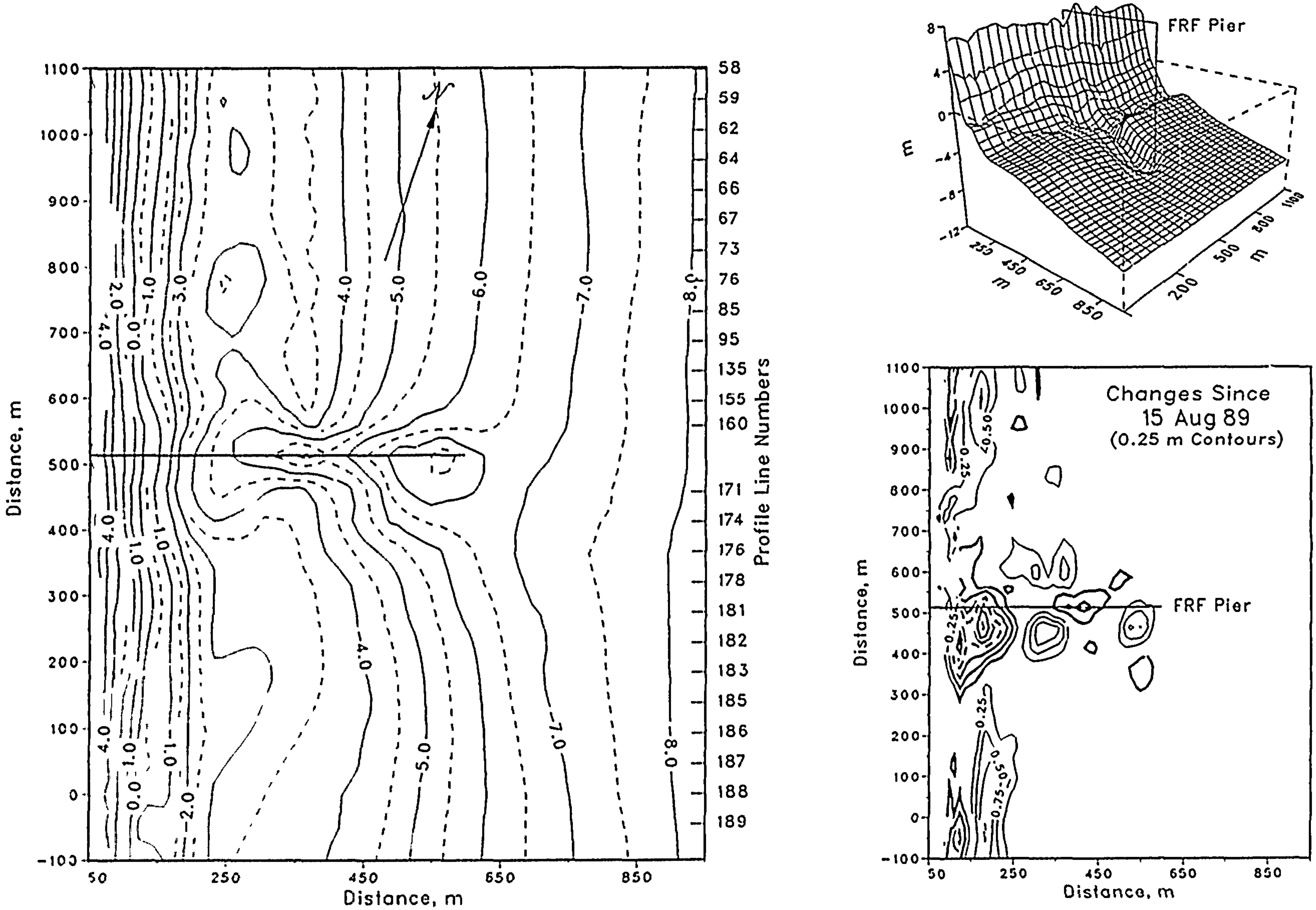


Figure A10. FRF Bathymetry 12 September 89 (depths relative to NGVD)

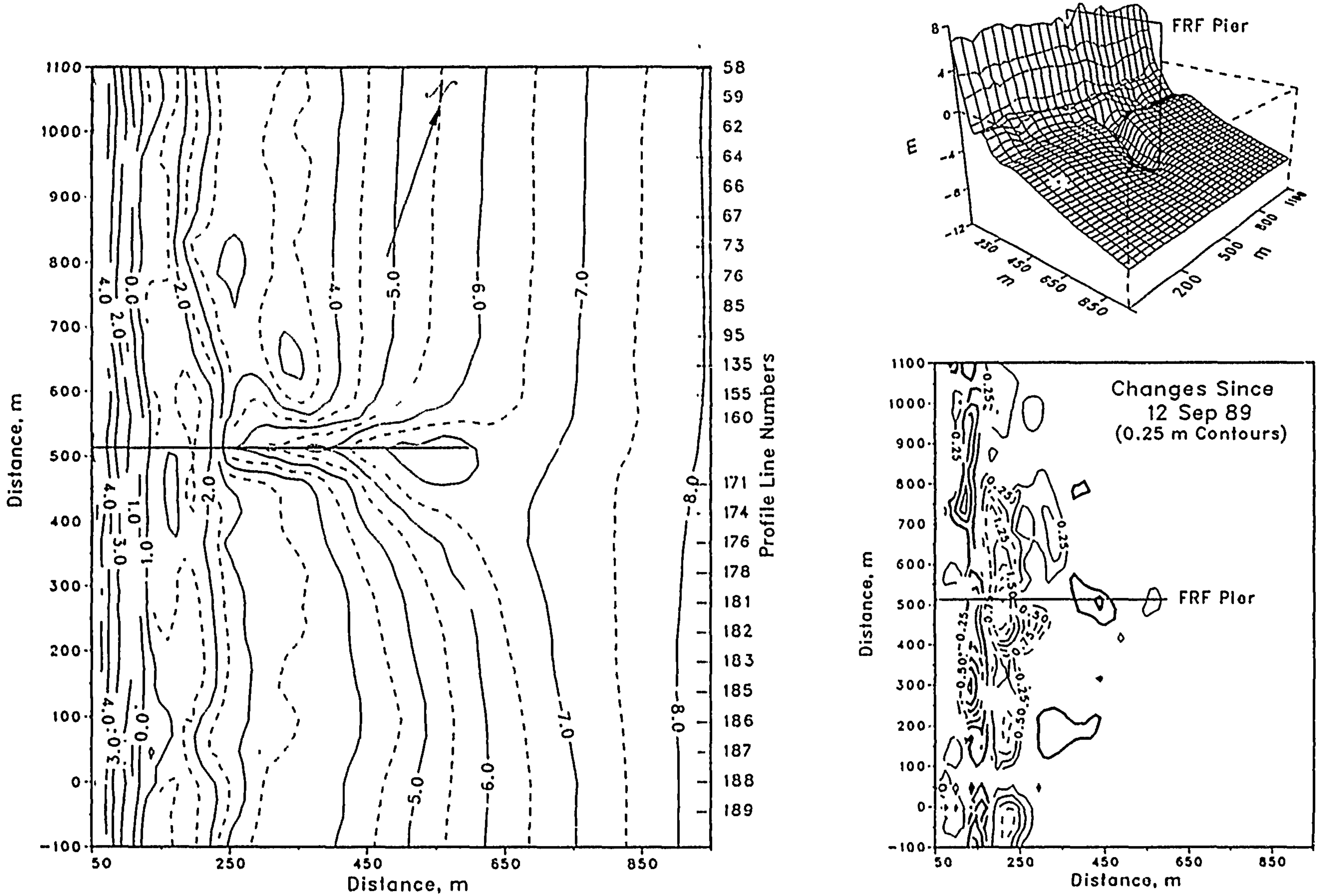
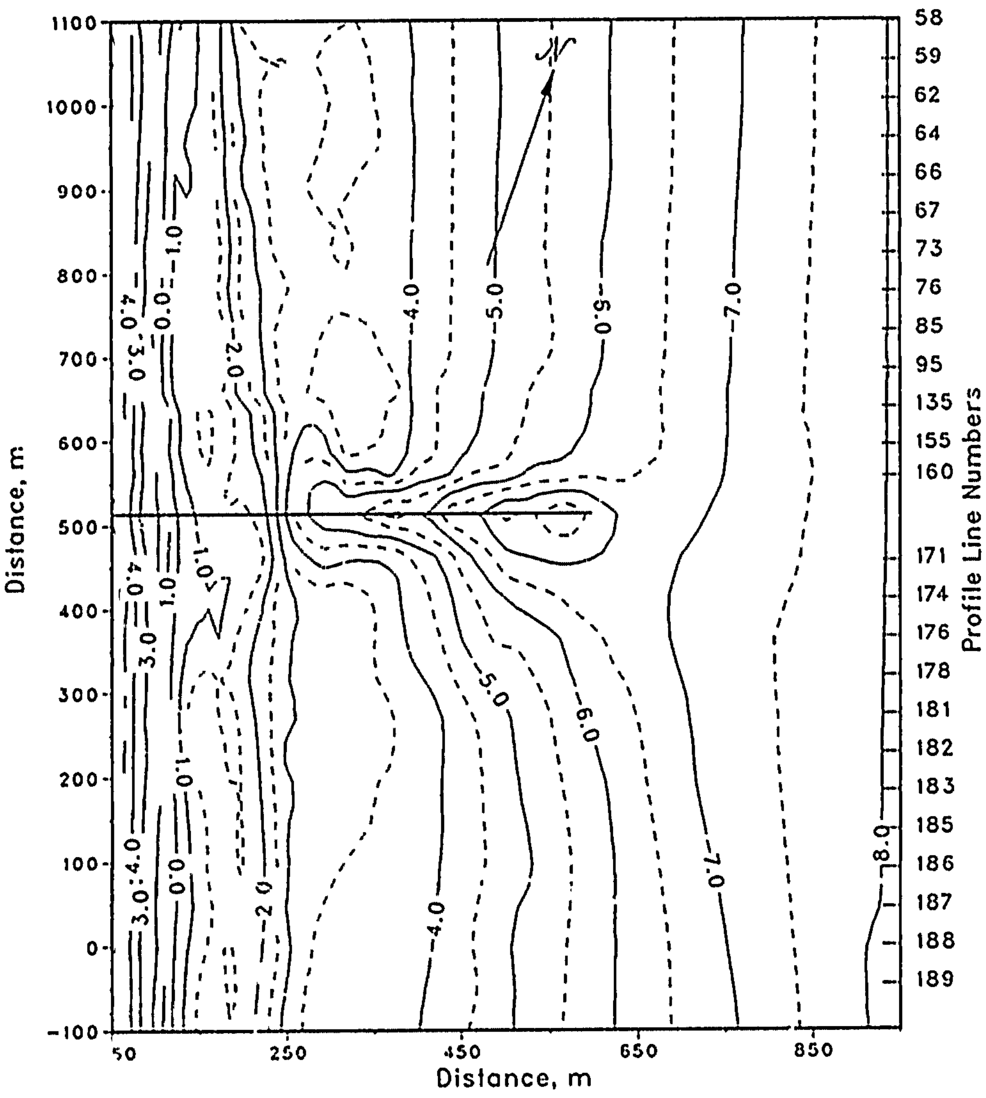
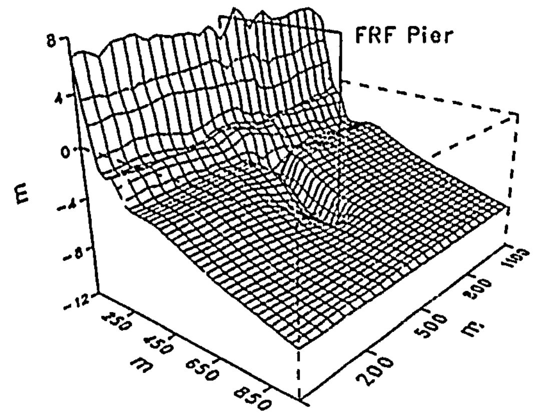


Figure A11. FRF Bathymetry 1 November 89 (depths relative to NGVD)





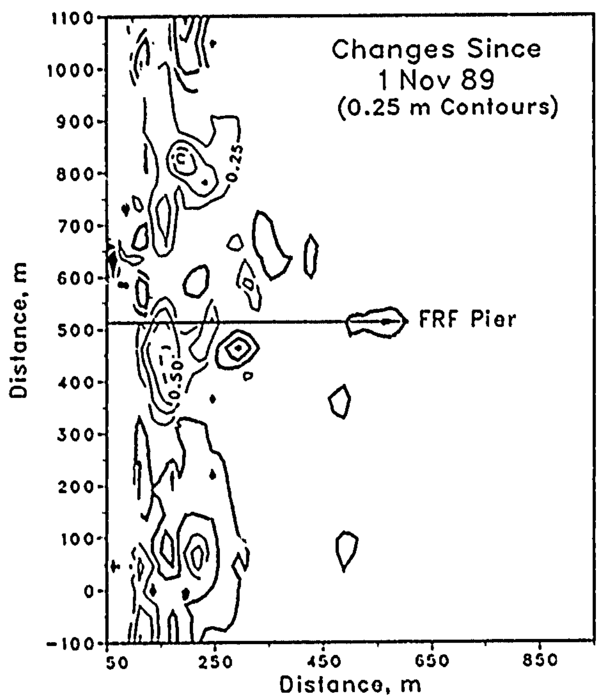


Figure A12. FRF Bathymetry 7 December 89 (depths relative to NGVD)

APPENDIX B: WAVE DATA FOR GAGE 630

1. Wave data summaries for Gage 630 are presented for 1989 and for 1980 through 1989 in the following forms:

Daily H_{mo} and T_p

2. Figure B1 displays the individual wave height and peak spectral wave period values along with the monthly mean values.

Joint Distributions of H_{mo} and T_p

3. Annual and monthly joint distributions tables are presented in Tables B1 and B2, and data for 1980 through 1989 are in Tables B3 and B4. Each table gives the frequency (in parts per 10,000) for which the wave height and peak period were within the specified intervals; these values can be converted to percentages by dividing by 100. Marginal totals are also included. The row total gives the total number of observations out of 10,000 that fell within each specified peak period interval. The column total gives the number of observations out of 10,000 that fell within each specified wave height interval.

Cumulative Distributions of Wave Height

4. Annual and monthly wave height distributions for 1989 are plotted in cumulative form in Figures B2 and B3. Data for 1980 through 1989 are in Figure B4.

Peak Spectral Wave Period Distributions

5. Annual and monthly peak wave period, T_p, distribution histograms for 1989 are presented in Figures B5 and B6. Data for 1980 through 1989 are in Figure B7.

Persistence of Wave Heights

6. Table B5 shows the number of times in 1989 when the specified wave height was equaled or exceeded at least once during each day for the duration (consecutive days). Data for 1980 through 1989 are given in Table B6. An example is shown below:

Height	Consecutive Day(s) or Longer																		
m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
0.5	18	15		14	13	12		11	10	9				8		7			
1.0	50	34	24	21	18	14	12	8	7	3			2						
1.5	41	19	8	6	2	1													
2.0	22	9	5	1															
2.5	10	5	2																
3.0	6	1																	
3.5		1																	
4.0	1																		

This example indicates that wave heights equaled or exceeded 1.0 m 50 times for at least 1 day; 34 times for at least 2 days; 24 times for at least 3 days, etc. Therefore, on 16 occasions the height equaled or exceeded 1.0 m for 1 day exactly (50 - 34 = 16); on 10 occasions for 2 days; on 3 occasions for 3 days, etc. Note that the height exceeded 1 m 50 times for 1 day or longer, while heights exceeded 0.5 m only 18 times for this same duration. This change in durations occurred because the longer durations of lower waves may be interspersed with shorter, but more frequent, intervals of higher waves. For example, one of the times that the wave heights exceeded 0.5 m for 16 days may have represented 3 times the height exceeded 1 m for shorter durations.

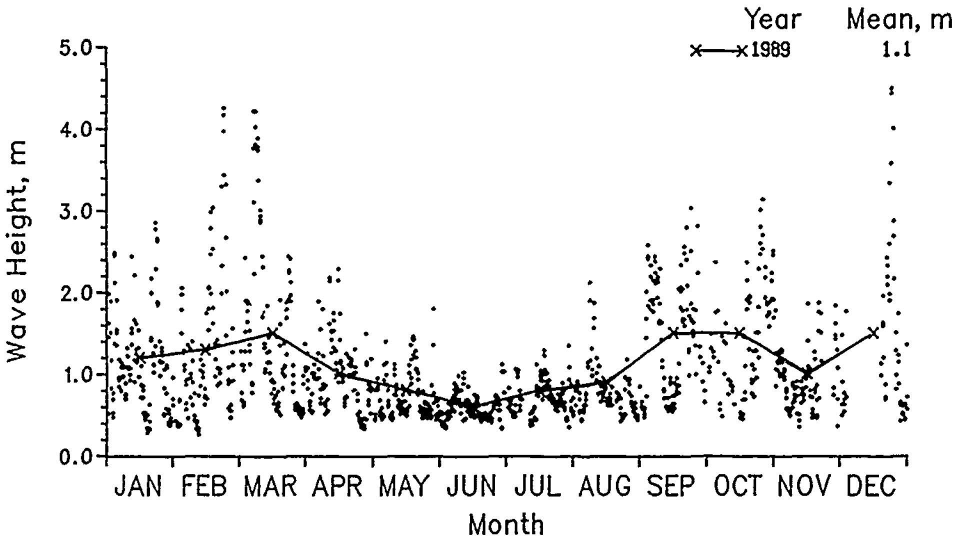
Spectra

7. Monthly spectra for the offshore Waverider buoy (Gage 630) are presented in Figure B8. The plots show "relative" energy density as a function of wave frequency. These figures summarize the large number of spectra for each month. The figures emphasize the higher energy density associated with storms as well as the general shifts in energy density to different frequencies. As used here, "relative" indicates the spectra have been smoothed by the three-dimensional surface drawing routine. Consequently, extremely high- and low-energy density values are modified to produce a smooth

surface. The figures are not intended for quantitative measurements; however, they do provide the energy density as a function of frequency relative to the other spectra for the month.

8. Monthly and annual wave statistics for Gage 630 for 1989 and for 1980 through 1989 are presented in Table B7.

9. Figure B9 plots monthly time-histories of wave height and period.



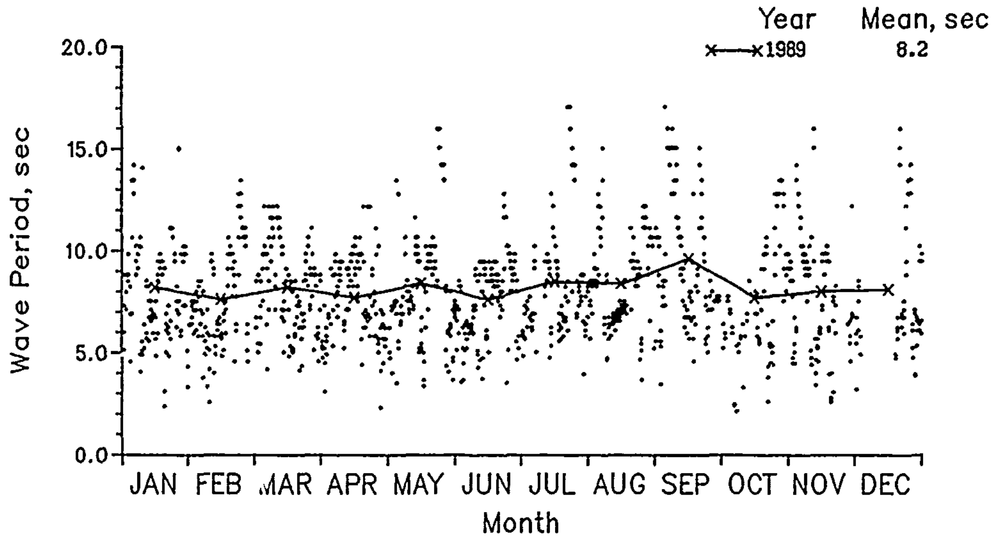


Figure B1. 1989 daily wave height and period values with monthly means for Gage 630

Table B1

Annual Joint Distribution of H_{mo} versus T_p

Annual 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	47	.	31	102	94	141	237	251	125	23	55	.	1206
0.50 - 0.99	31	188	258	626	807	619	752	767	509	125	243	16	4941
1.00 - 1.49	.	.	188	368	446	258	180	227	149	70	39	.	1925
1.50 - 1.99	.	.	8	188	227	149	94	125	78	47	86	8	1010
2.00 - 2.49	.	.	.	16	149	31	125	47	23	55	63	.	509
2.50 - 2.99	.	.	.	.	.	47	31	16	31	8	55	.	188
3.00 - 3.49	.	.	.	.	.	39	8	8	16	8	8	.	87
3.50 - 3.99	.	.	.	.	.	.	8	.	39	.	16	.	63
4.00 - 4.49	.	.	.	.	.	.	.	16	16	8	23	.	63
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	8	.	.	.	8
Total	78	188	485	1300	1723	1284	1535	1457	994	344	588	24	

Table B2

Monthly Joint Distribution of H_{mo} versus T_p

January 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	83	.	.	.	.	83	83	826	165	.	.	.	1240
0.50 - 0.99	.	165	248	248	413	248	661	661	248	165	248	.	3305
1.00 - 1.49	.	.	331	826	579	579	331	331	83	248	.	.	3308
1.50 - 1.99	.	.	.	165	413	83	248	.	248	83	.	.	1240
2.00 - 2.49	.	.	.	.	331	.	248	.	.	.	.	.	579
2.50 - 2.99	.	.	.	.	.	.	.	.	331	.	.	.	331
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	83	165	579	1239	1736	993	1571	1818	1075	496	248	0	

February 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	95	.	95	286	381	286	190	476	190	.	.	.	1999
0.50 - 0.99	.	190	381	571	571	286	95	286	476	.	.	.	2856
1.00 - 1.49	.	.	190	762	286	286	381	286	286	.	.	.	2477
1.50 - 1.99	.	.	.	286	286	190	95	95	95	.	.	.	1047
2.00 - 2.49	.	.	.	.	381	95	.	.	.	.	95	.	571
2.50 - 2.99	.	.	.	.	.	190	95	.	.	.	95	.	380
3.00 - 3.49	.	.	.	.	.	95	95	95	.	95	.	.	380
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	95	.	95
4.00 - 4.49	.	.	.	.	.	.	.	.	95	.	95	.	190
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	95	190	666	1905	1905	1428	951	1238	1142	95	380	0	

March 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	.	81	.	.	81	.	.	.	.	.	162
0.50 - 0.99	.	.	325	732	163	407	1301	569	325	.	.	.	3822
1.00 - 1.49	.	.	81	325	407	569	407	163	488	.	81	.	2521
1.50 - 1.99	.	.	.	163	488	244	163	325	163	.	.	.	1546
2.00 - 2.49	.	.	.	.	163	.	244	163	81	.	81	.	732
2.50 - 2.99	.	.	.	.	.	81	163	.	.	.	.	.	244
3.00 - 3.49	.	.	.	.	.	163	.	.	81	.	.	.	244
3.50 - 3.99	.	.	.	.	.	.	.	.	407	.	81	.	488
4.00 - 4.49	.	.	.	.	.	.	.	81	81	.	81	.	243
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	0	406	1301	1221	1464	2359	1301	1626	0	324	0	

(Continued)

(Sheet 1 of 4)

April 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	85	.	.	342	85	85	171	85	171	.	.	.	1024
0.50 - 0.99	.	85	256	769	684	171	684	1538	171	.	171	.	4529
1.00 - 1.49	.	.	256	256	940	598	256	598	85	.	85	.	3074
1.50 - 1.99	.	.	.	171	256	171	171	171	85	.	.	.	1025
2.00 - 2.49	.	.	.	.	171	.	85	85	.	.	.	.	341
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	85	85	512	1538	2136	1025	1367	2477	512	0	256	0	

May 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	164	.	246	164	656	82	82	246	164	.	1804
0.50 - 0.99	.	328	410	656	820	1557	656	492	656	492	492	.	6559
1.00 - 1.49	.	.	82	246	164	164	82	656	164	.	.	.	1558
1.50 - 1.99	.	.	.	.	82	.	.	.	.	.	.	.	82
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	328	656	902	1312	1885	1394	1230	902	738	656	0	

June 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	.	339	169	424	1441	593	339	.	85	.	3390
0.50 - 0.99	.	339	339	1017	1102	678	1356	1186	169	.	85	.	6271
1.00 - 1.49	.	.	169	169	.	.	.	.	.	.	.	.	338
1.50 - 1.99	.	.	.	.	.	.	.	.	.	.	.	.	0
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	339	508	1525	1271	1102	2797	1779	508	0	170	0	

(Continued)

(Sheet 2 of 4)

Table B2 (Continued)

July 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	92	92	.	459	459	367	.	.	.	.	1469
0.50 - 0.99	.	92	92	642	1743	917	1284	734	459	459	642	183	7247
1.00 - 1.49	.	.	.	183	917	.	.	.	183	.	.	.	1283
1.50 - 1.99	.	.	.	.	.	.	.	.	.	.	.	.	0
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	92	184	917	2660	1376	1743	1101	642	459	642	183	

August 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	.	.	.	.	446	89	268	.	.	.	803
0.50 - 0.99	.	89	89	357	1518	1339	1161	1161	1339	.	625	.	7678
1.00 - 1.49	.	.	179	179	357	.	.	.	89	89	89	.	982
1.50 - 1.99	.	.	.	179	268	.	.	.	.	.	.	.	447
2.00 - 2.49	.	.	.	.	89	.	.	.	.	.	.	.	89
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	89	268	715	2232	1339	1607	1250	1696	89	714	0	

September 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	.	.	.	.	90	.	.	.	.	.	90
0.50 - 0.99	.	90	.	270	631	991	541	270	991	.	90	.	3874
1.00 - 1.49	.	.	90	180	.	270	90	90	180	180	.	.	1080
1.50 - 1.99	.	.	.	360	180	270	180	180	270	180	631	90	2341
2.00 - 2.49	.	.	.	90	90	180	631	.	90	450	541	.	2072
2.50 - 2.99	.	.	.	.	.	180	90	.	.	90	90	.	450
3.00 - 3.49	.	.	.	.	.	90	.	.	.	.	.	.	90
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	90	90	900	901	1981	1622	540	1531	900	1352	90	

(Continued)

(Sheet 3 of 4)

Table B2 (Concluded)

October 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	120	.	.	.	120	120	120	.	.	.	.	.	480
0.50 - 0.99	361	241	.	843	602	.	120	120	241	.	.	.	2528
1.00 - 1.49	.	.	241	964	482	241	.	120	120	.	.	.	2168
1.50 - 1.99	.	.	120	482	.	482	241	723	.	361	361	.	2770
2.00 - 2.49	.	.	.	120	120	120	241	361	120	120	.	.	1202
2.50 - 2.99	.	.	.	.	.	.	.	241	.	.	361	.	602
3.00 - 3.49	.	.	.	.	.	.	.	.	120	.	120	.	240
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	481	241	361	2409	1324	963	722	1565	601	481	842	0	

November 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	206	.	.	.	.	.	.	206	103	.	412	.	927
0.50 - 0.99	103	309	619	825	412	103	309	1546	825	.	206	.	5257
1.00 - 1.49	.	.	412	206	825	206	515	309	.	206	206	.	2885
1.50 - 1.99	.	.	.	206	206	412	.	103	.	.	.	.	927
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	309	309	1031	1237	1443	721	824	2164	928	206	824	0	

December 1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	.	.	.	.	169	.	.	169	169	.	.	.	507
0.50 - 0.99	.	508	339	678	1186	339	339	339	.	508	339	.	4575
1.00 - 1.49	.	.	339	169	508	.	.	.	.	169	.	.	1185
1.50 - 1.99	.	.	.	508	678	.	.	.	.	.	169	.	1355
2.00 - 2.49	.	.	.	.	678	.	.	.	.	169	.	.	847
2.50 - 2.99	.	.	.	.	.	169	.	.	.	.	339	.	508
3.00 - 3.49	.	.	.	.	.	169	.	.	.	.	.	.	169
3.50 - 3.99	.	.	.	.	.	.	169	.	.	.	.	.	169
4.00 - 4.49	.	.	.	.	.	.	.	169	.	169	169	.	507
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	169	.	.	.	169
Total	0	508	678	1355	3219	677	508	677	338	1015	1016	0	

(Sheet 4 of 4)

Table B3

Annual Joint Distribution of H_{mo} versus T_p (All Years)

Annual 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	30	16	28	66	94	118	329	278	193	70	126	3	1351
0.50 - 0.99	38	134	254	512	596	525	849	722	781	149	216	15	4791
1.00 - 1.49	.	9	140	398	450	264	239	203	339	42	122	4	2210
1.50 - 1.99	.	.	13	159	253	113	81	76	133	36	78	5	947
2.00 - 2.49	.	.	2	25	85	70	57	42	66	32	43	2	424
2.50 - 2.99	.	.	.	1	8	33	18	16	37	10	26	.	149
3.00 - 3.49	.	.	.	.	1	12	14	13	17	5	9	.	71
3.50 - 3.99	.	.	.	.	.	1	6	6	13	4	5	.	35
4.00 - 4.49	.	.	.	.	.	.	2	3	8	2	4	.	19
4.50 - 4.99	.	.	.	.	.		.	1	2	.	.	.	3
5.00 - Greater	.	.	.	.	.	.	1	.	1	2	1	.	5
Total	68	159	437	1161	1487	1136	1596	1360	1590	352	630	29	

Table B4

Monthly Joint Distribution of H_{m0} versus T_p (All Years)

January 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	103	9	.	93	75	37	159	168	215	56	93	.	1008
0.50 - 0.99	65	224	252	355	392	336	345	514	803	121	252	.	3659
1.00 - 1.49	.	19	187	542	560	261	187	196	532	28	65	9	2586
1.50 - 1.99	.	.	28	355	458	215	112	103	243	28	56	.	1598
2.00 - 2.49	.	.	.	28	205	196	112	28	112	37	28	9	755
2.50 - 2.99	.	.	.	.	19	75	47	19	75	19	47	.	301
3.00 - 3.49	.	.	.	.	.	9	28	9	28	.	.	.	74
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	9	.	.	.	9
4.50 - 4.99	.	.	.	.	.	.	.	.	9	.	.	.	9
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	168	252	467	1373	1709	1129	990	1037	2026	289	541	18	

February 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	10	.	10	50	69	50	99	50	59	30	119	.	546
0.50 - 0.99	59	89	178	465	465	248	495	644	1050	20	129	10	3652
1.00 - 1.49	.	10	119	634	614	238	307	347	574	79	198	.	3120
1.50 - 1.99	.	.	10	198	356	198	109	99	208	59	99	.	1336
2.00 - 2.49	.	.	.	89	149	30	40	79	89	50	109	.	635
2.50 - 2.99	.	.	.	10	10	50	10	10	109	20	69	.	288
3.00 - 3.49	.	.	.	.	.	20	10	30	30	20	20	.	130
3.50 - 3.99	.	.	.	.	.	.	.	10	10	.	10	.	30
4.00 - 4.49	.	.	.	.	.	.	.	10	40	.	10	.	60
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	10	.	.	.	.	.	10
Total	69	99	317	1446	1663	834	1080	1279	2169	278	763	10	

March 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	9	.	.	18	45	45	80	36	107	54	54	.	448
0.50 - 0.99	9	80	205	455	473	419	607	749	812	134	161	.	4104
1.00 - 1.49	.	9	196	401	526	366	294	285	687	54	303	.	3121
1.50 - 1.99	.	.	9	232	259	116	89	125	241	80	125	.	1276
2.00 - 2.49	.	.	.	18	62	27	89	62	152	36	107	.	553
2.50 - 2.99	.	.	.	.	18	18	27	9	54	18	45	.	169
3.00 - 3.49	.	.	.	.	9	18	9	18	54	9	9	.	126
3.50 - 3.99	.	.	.	.	.	.	.	18	62	.	18	.	98
4.00 - 4.49	.	.	.	.	.	.	9	18	18	.	27	.	72
4.50 - 4.99	.	.	.	.	.	.	.	.	18	.	.	.	18
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	18	89	410	1124	1392	1009	1204	1320	2205	385	849	0	

(Continued)

(Sheet 1 of 4)

Table B4 (Continued)

April 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	9	9	18	55	37	27	293	211	183	92	92	.	1026
0.50 - 0.99	82	183	266	430	522	476	678	788	1026	256	394	.	5101
1.00 - 1.49	.	9	119	229	430	348	321	321	339	55	147	.	2318
1.50 - 1.99	.	.	.	147	137	101	101	119	201	27	101	.	934
2.00 - 2.49	.	.	.	37	46	9	55	64	55	27	9	.	302
2.50 - 2.99	.	.	.	.	9	18	27	18	37	27	18	.	154
3.00 - 3.49	.	.	.	.	.	27	18	27	27	.	.	.	99
3.50 - 3.99	.	.	.	.	.	9	37	.	.	.	.	.	46
4.00 - 4.49	.	.	.	.	.	.	9	.	.	.	.	.	9
4.50 - 4.99	.	.	.	.	.	.	.	9	.	.	.	.	9
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	91	201	403	898	1181	1015	1539	1557	1868	484	761	0	

May 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	9	18	45	81	145	163	471	235	145	45	72	.	1429
0.50 - 0.99	18	172	335	624	588	805	1240	1032	706	81	199	.	5800
1.00 - 1.49	.		90	235	317	217	407	244	317	9	81	.	1917
1.50 - 1.99	.	.	9	45	90	36	118	72	109	27	63	.	569
2.00 - 2.49	.	.	.	18	18	54	.	36	9	27	27	.	189
2.50 - 2.99	.	.	.	.	9	9	9	9	9	18	9	.	72
3.00 - 3.49	.	.		.	.	.	.	.	.	9	9	.	18
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	27	190	479	1003	1167	1284	2245	1628	1295	216	460	0	

June 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	29	38	57	144	220	383	727	584	220	38	38	.	2478
0.50 - 0.99	48	249	373	699	708	727	1617	928	526	153	38	.	6056
1.00 - 1.49	.	.	86	201	201	172	172	96	96	.	48	.	1072
1.50 - 1.99	.	.	19	48	67	57	19	10	67	.	10	.	297
2.00 - 2.49	.	.	.	.	19	19	38	10	.	.	.	.	86
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	77	287	535	1092	1215	1358	2573	1628	909	191	134	0	

(Continued)

(Sheet 2 of 4)

Table B4 (Continued)

July 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	9	19	57	104	218	303	1041	747	293	114	227	19	3151
0.50 - 0.99	38	132	293	643	899	795	1466	899	416	246	132	76	6035
1.00 - 1.49	.	19	47	170	265	76	47	38	19	.	.	.	691
1.50 - 1.99	.	.	.	47	9	19	28	.	.	.	.	.	103
2.00 - 2.49	.	.	.	9	.	.	9	.	.	.	.	.	18
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	47	170	397	973	1391	1193	2591	1684	728	360	359	95	

August 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	28	28	66	123	160	169	471	452	358	66	94	.	2035
0.50 - 0.99	28	94	226	613	905	829	1385	829	622	170	311	.	6012
1.00 - 1.49	.	9	151	368	292	207	141	94	66	19	9	.	1356
1.50 - 1.99	.	.	.	75	151	66	28	19	19	.	28	.	386
2.00 - 2.49	.	.	.	19	28	9	19	.	38	.	9	.	122
2.50 - 2.99	.	.	.	.	9	.	19	.	9	.	9	.	46
3.00 - 3.49	.	.	.	.	.	9	9	.	9	.	.	.	27
3.50 - 3.99	.	.	.	.	.	.	.	9	.	.	.	.	9
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	56	131	443	1198	1545	1309	2072	1403	1121	255	460	0	

September 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
	Period, sec												
0.00 - 0.49	9	9	9	28	28	19	93	299	243	112	93	9	951
0.50 - 0.99	.	56	168	401	588	570	784	747	1027	131	233	.	4705
1.00 - 1.49	.	9	84	411	542	345	411	205	336	93	159	9	2604
1.50 - 1.99	.	.	9	140	289	140	93	121	75	28	131	9	1035
2.00 - 2.49	.	.	.	37	84	56	84	28	75	75	75	.	514
2.50 - 2.99	.	.	.	.	.	47	28	9	.	9	9	.	102
3.00 - 3.49	.	.	.	.	.	9	.	9	9	9	9	.	45
3.50 - 3.99	.	.	.	.	.	.	.	.	9	9	9	.	27
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	9	.	.	9
Total	9	74	270	1017	1531	1165	1493	1418	1774	475	718	27	

(Continued)

(Sheet 3 of 4)

Table B4 (Concluded)

October 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	36	.	.	.	53	71	196	152	241	36	134	.	919
0.50 - 0.99	36	53	134	374	419	348	633	455	936	160	294	9	3851
1.00 - 1.49	.	.	169	624	348	214	125	232	428	80	214	.	2434
1.50 - 1.99	.	.	36	214	392	107	89	116	187	116	223	36	1516
2.00 - 2.49	.	.	.	18	116	187	71	98	143	53	80	9	775
2.50 - 2.99	.	.	.	.	18	116	36	71	45	9	62	.	357
3.00 - 3.49	.	.	.	.	.	36	9	.	18	.	36	.	99
3.50 - 3.99	.	.	.	.	.	.	.	18	.	18	.	.	36
4.00 - 4.49	.	.	.	.	.	.	.	.	18	.	.	.	18
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	72	53	339	1230	1346	1079	1159	1142	2016	472	1043	54	

November 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	31	31	31	21	52	104	167	177	94	63	219	.	990
0.50 - 0.99	42	104	397	595	564	470	459	564	595	136	146	52	4124
1.00 - 1.49	.	21	282	532	731	428	261	251	292	42	94	31	2965
1.50 - 1.99	.	.	21	209	334	219	125	73	115	52	10	10	1168
2.00 - 2.49	.	.	.	31	73	125	136	42	21	21	10	.	459
2.50 - 2.99	.	.	.	.	.	21	10	21	52	.	10	.	114
3.00 - 3.49	.	.	.	.	.	.	21	52	.	10	10	.	93
3.50 - 3.99	.	.	.	.	.	.	.	.	42	21	10	.	73
4.00 - 4.49	.	.	.	.	.	.	.	.	.	10	.	.	10
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	73	156	731	1388	1754	1367	1179	1180	1211	355	509	93	

December 1980-1989, Gage 630
Percent Occurrence(X100) of Height and Period

Height, m	Period, sec 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	85	32	53	74	21	21	127	233	137	148	307	11	1249
0.50 - 0.99	32	180	243	507	645	243	412	476	835	169	296	42	4080
1.00 - 1.49	.	.	159	455	634	307	190	116	359	42	137	.	2399
1.50 - 1.99	.	.	11	201	529	95	53	42	116	11	74	.	1132
2.00 - 2.49	.	.	21	.	243	127	32	53	85	53	63	.	677
2.50 - 2.99	.	.	.	.	.	42	.	21	63	.	32	.	158
3.00 - 3.49	.	.	.	.	.	11	74	21	21	.	11	.	138
3.50 - 3.99	.	.	.	.	.	.	32	21	32	.	11	.	96
4.00 - 4.49	.	.	.	.	.	.	.	11	11	11	11	.	44
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	11	11	11	.	33
Total	117	212	487	1237	2072	846	920	994	1670	445	953	53	

(Sheet 4 of 4)

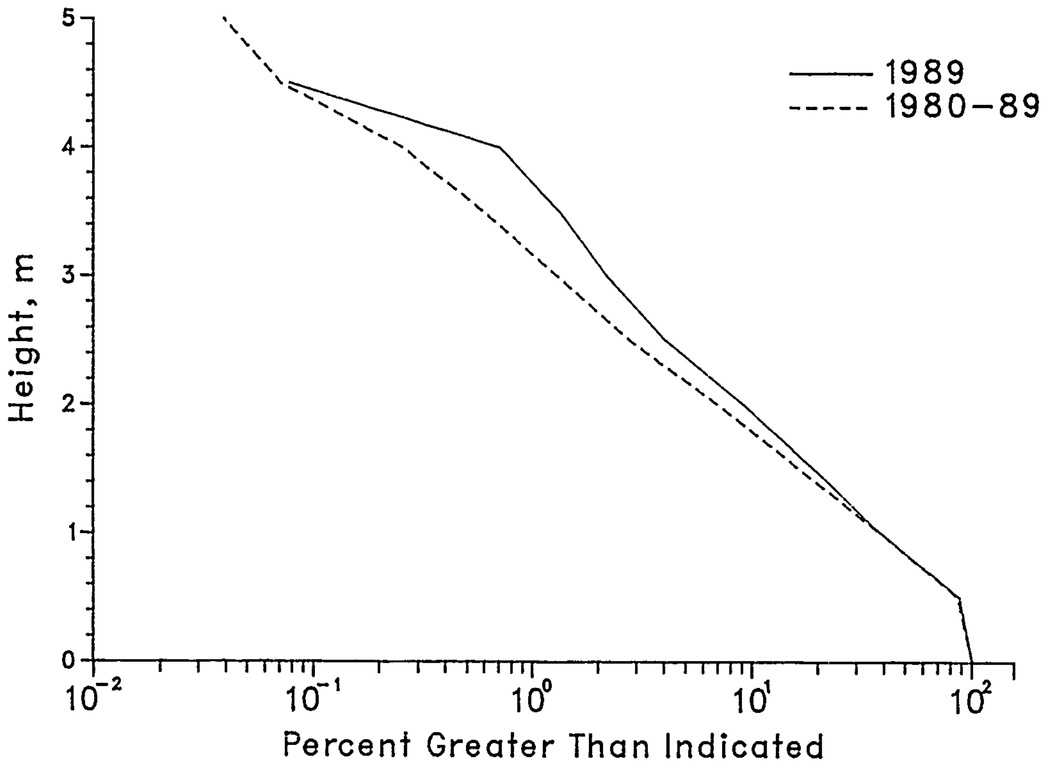


Figure B2. Annual cumulative wave height distributions for Gage 630

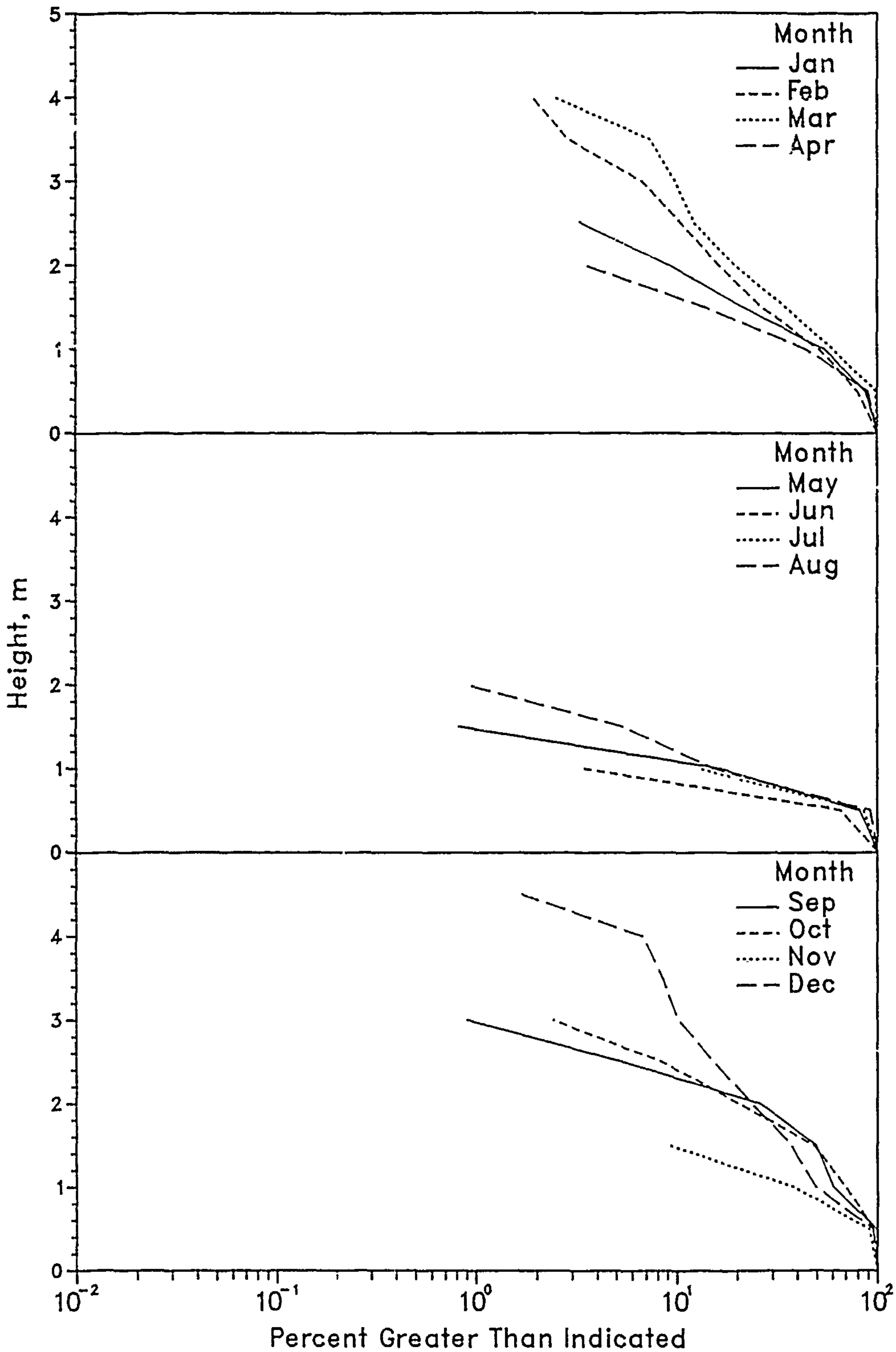


Figure B3. 1989 monthly wave height distributions for Gage 630

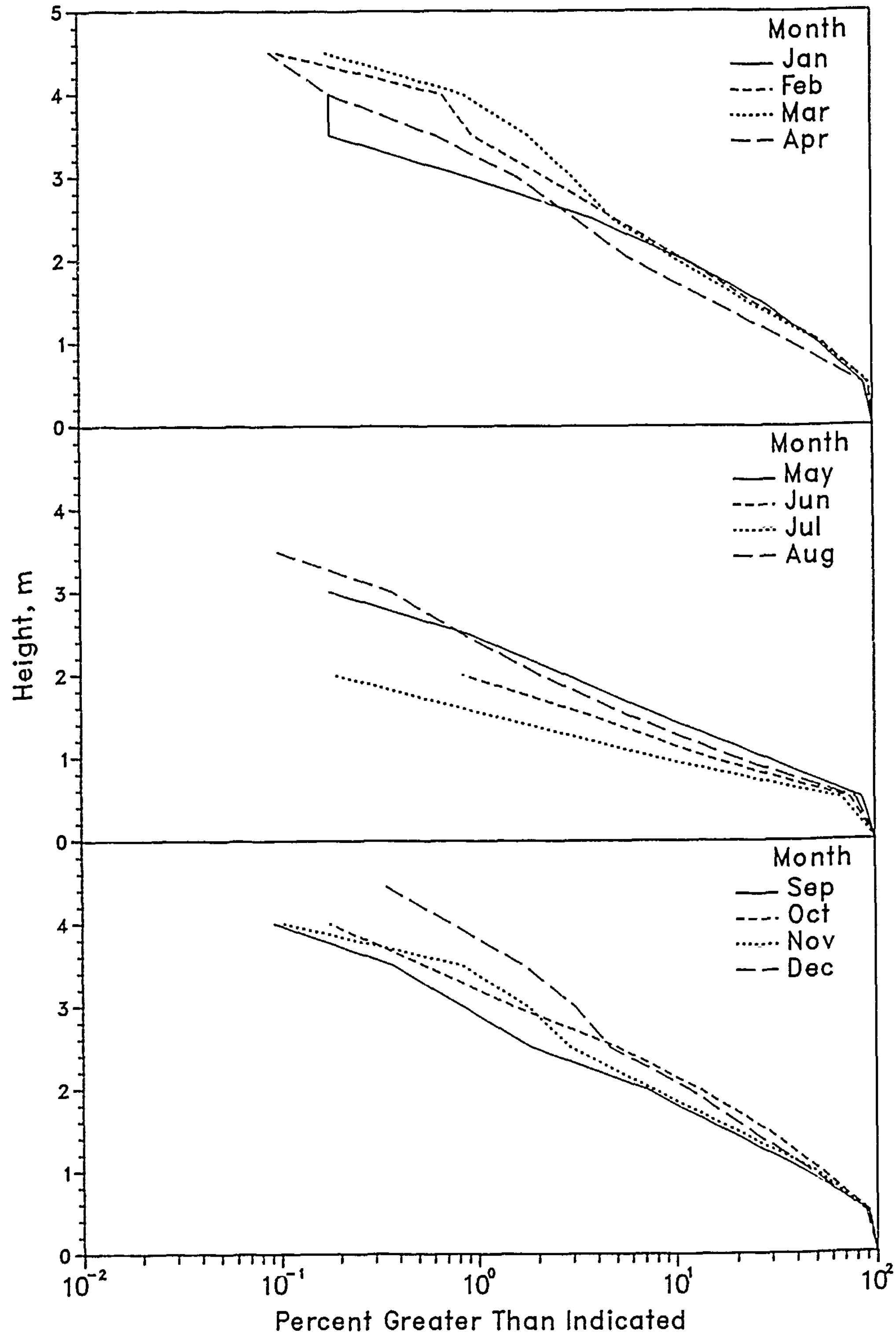


Figure B4. 1980-1989 monthly wave height distributions for Gage 630

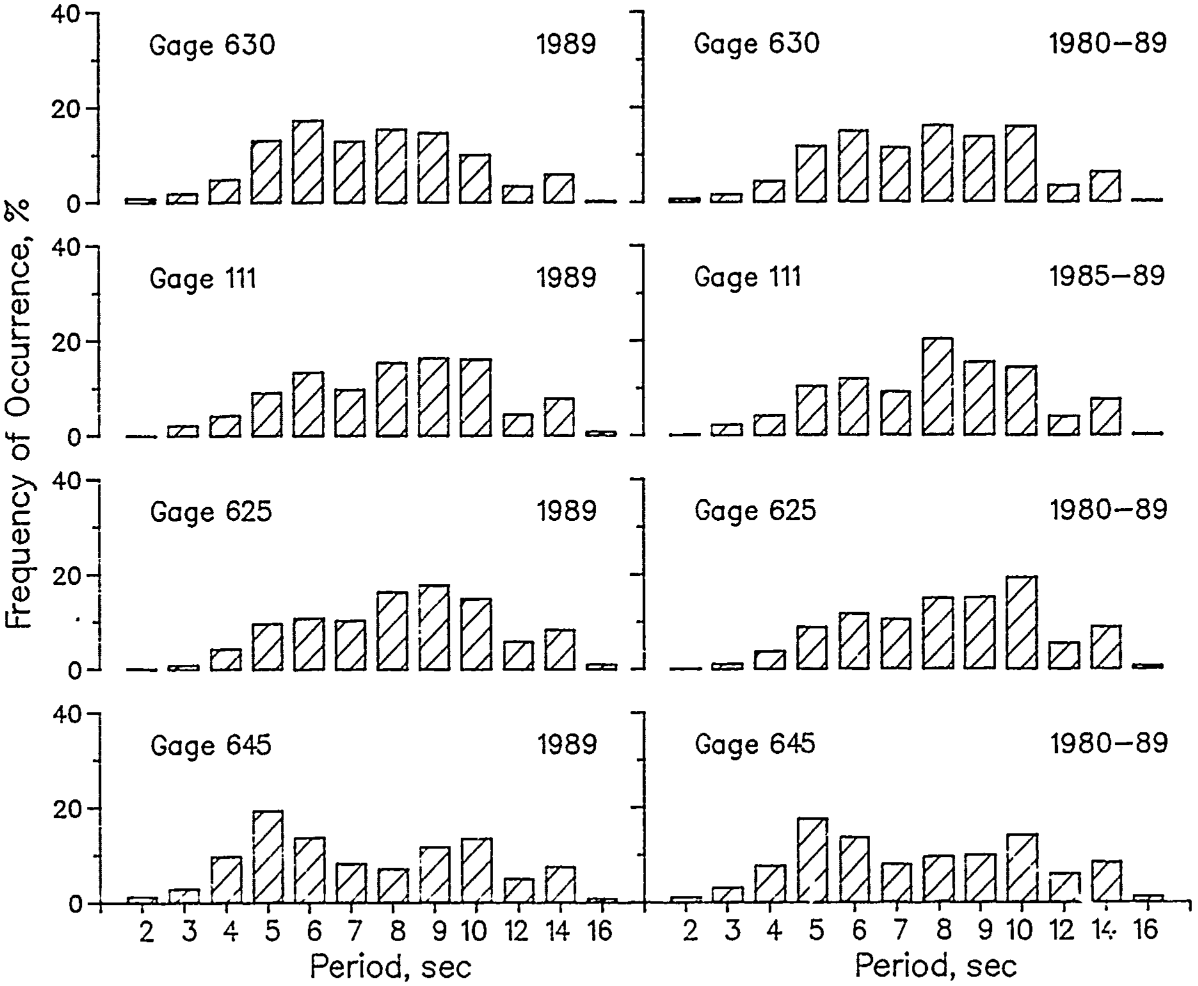


Figure B5. Annual wave period distributions for all gages

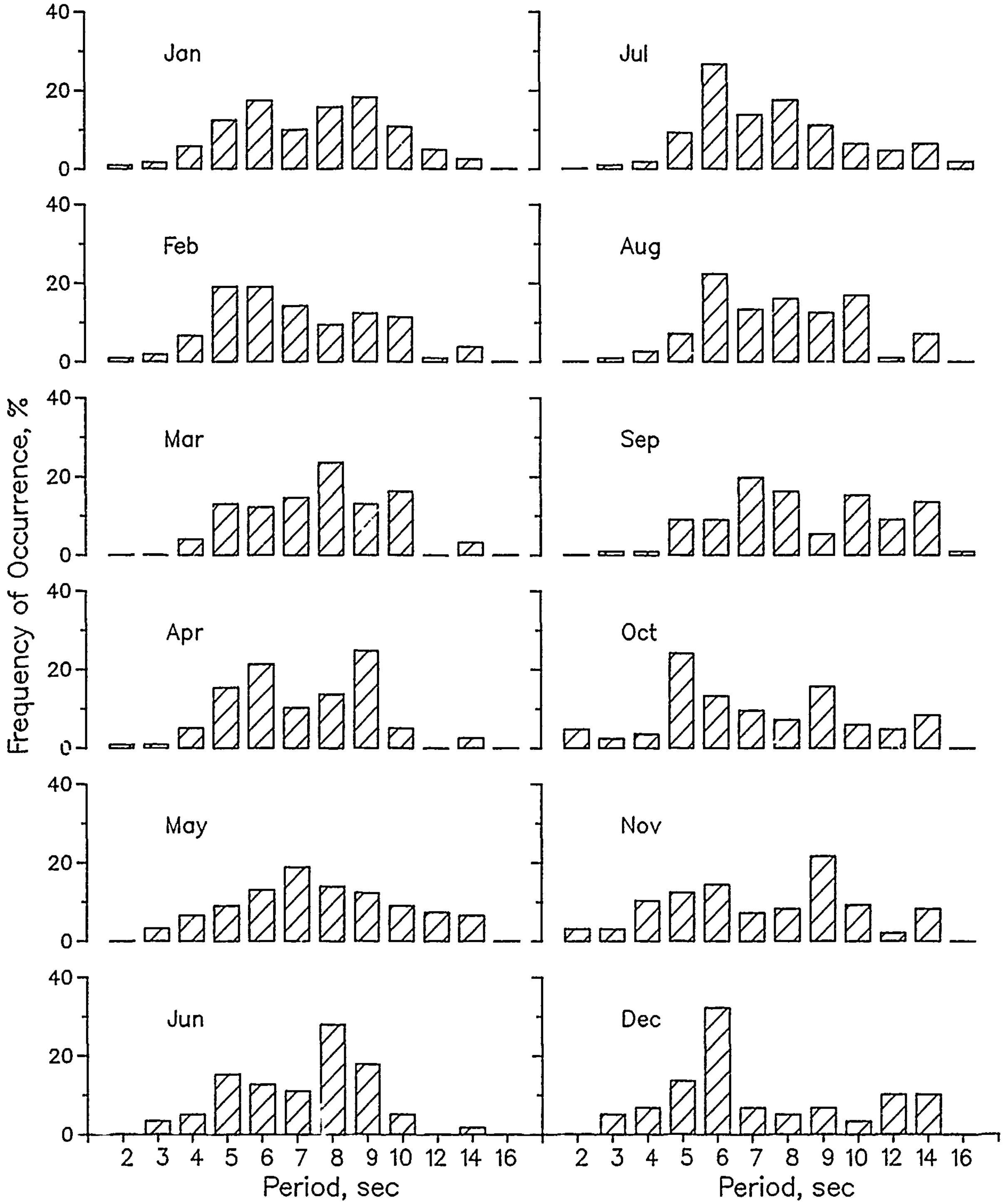


Figure B6. 1989 monthly wave period distributions for Gage 630

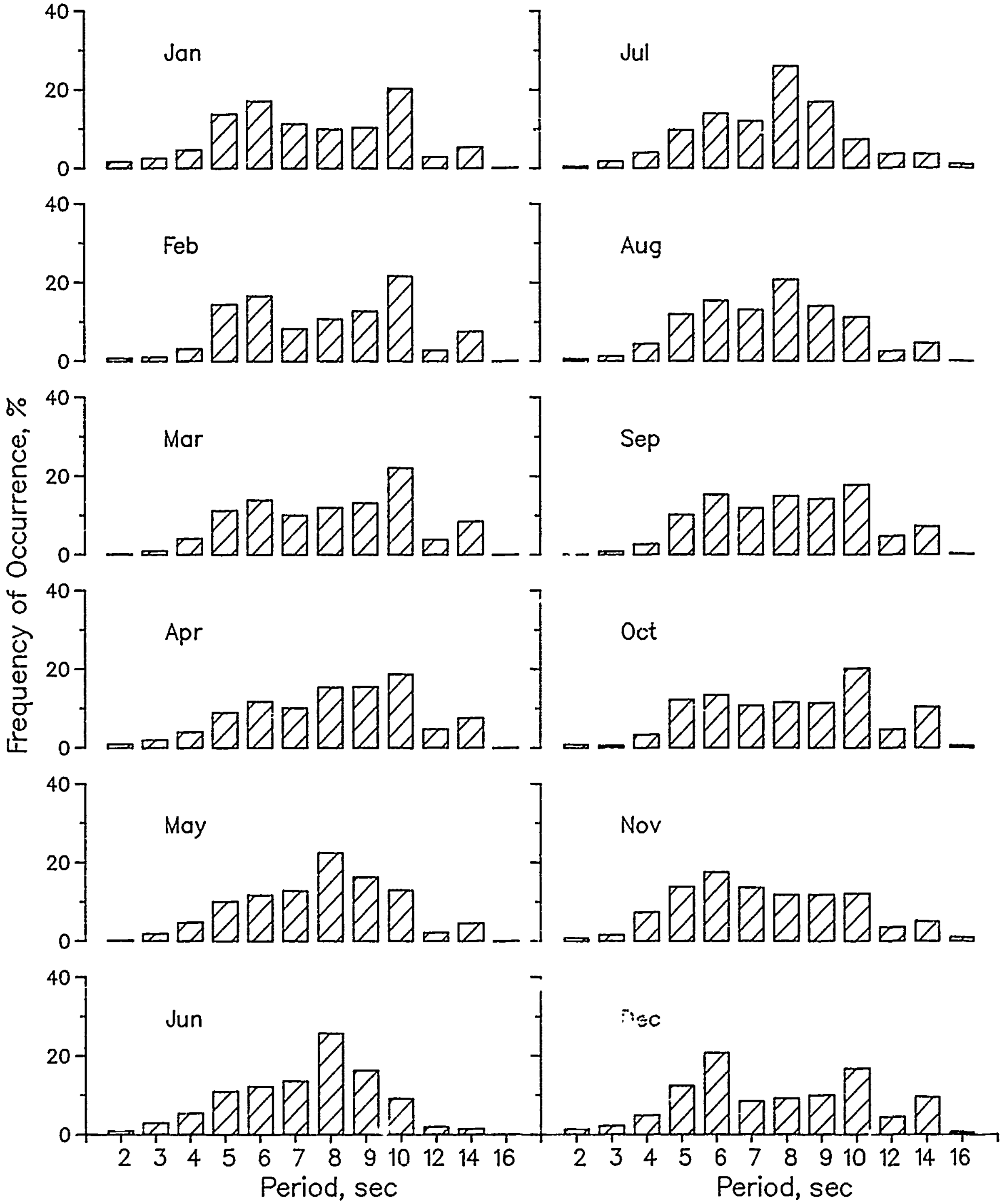


Figure B7. 1980-1989 monthly wave period distributions for Gage 630

Table B5

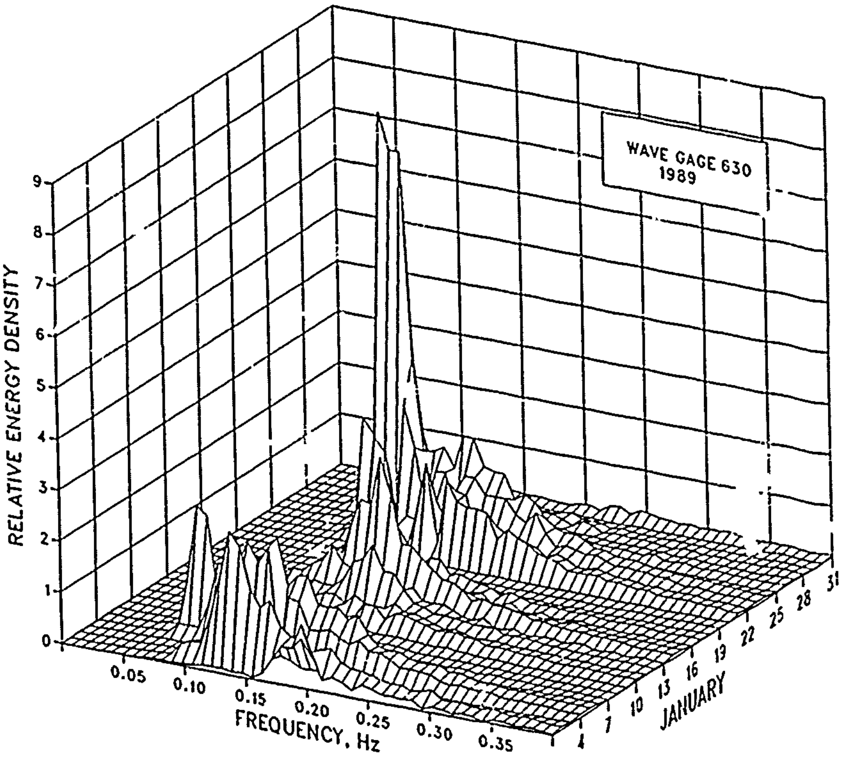
1989 Persistence of H_{mo} for Gage 630

Height (m)	Consecutive Day(s) or Longer 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
0.5	16						15		13					11	10	9		8	6
1.0	48	34		22	18	12	9			6	4	[illegible]	2						1
1.5	34	20	13		9		5	4	3	2									
2.0	25	12	8	5		3	1												
2.5	13	8	4	1															
3.0	7	5	4	1															
3.5	4	3	2																
4.0	4	3																	

Table B6

1980 through 1989 Persistence of H_{mo} for Gage 630

Height (m)	Consecutive Day(s) or Longer 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
0.5	21	18	16	15		14	12	11		10			9	7	6	5			4
1.0	50	33	24	18	14	10	8	5	4	3		2					1		
1.5	39	21	11	6	5		2		1										
2.0	22	11	5	2		1													
2.5	11	5	2																
3.0	6	2	1																
3.5	3	1																	
4.0	1																		



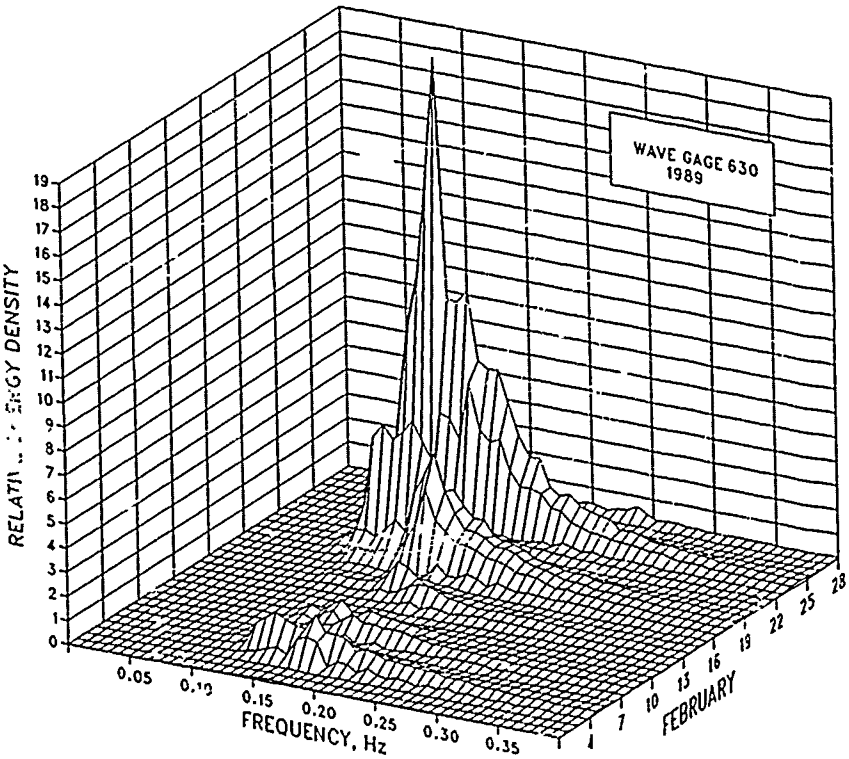
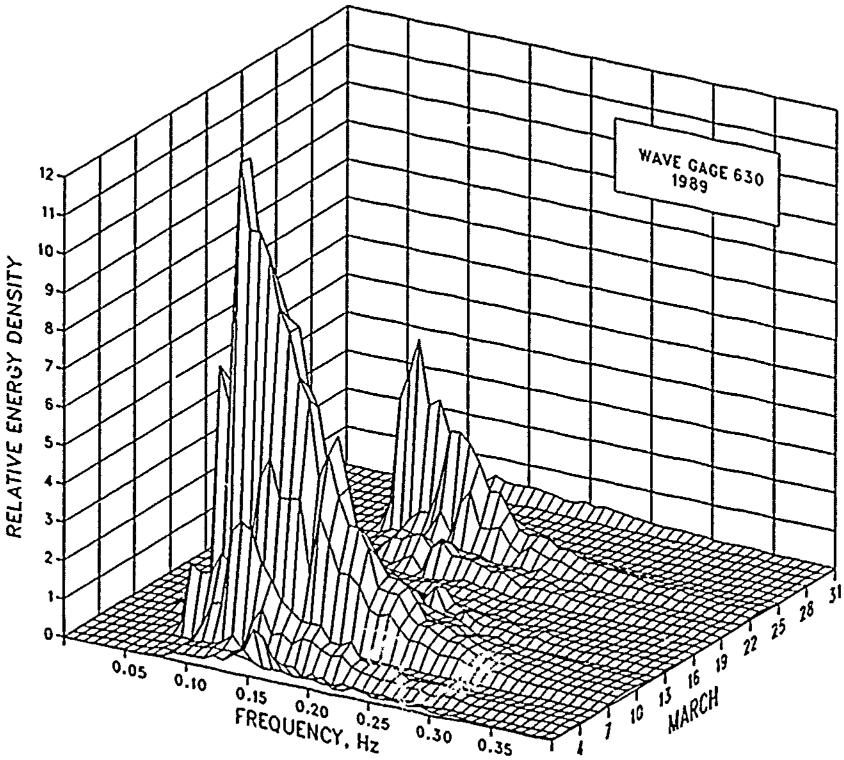


Figure B8. 1989 monthly spectra for Gage 630
(Sheet 1 of 6)



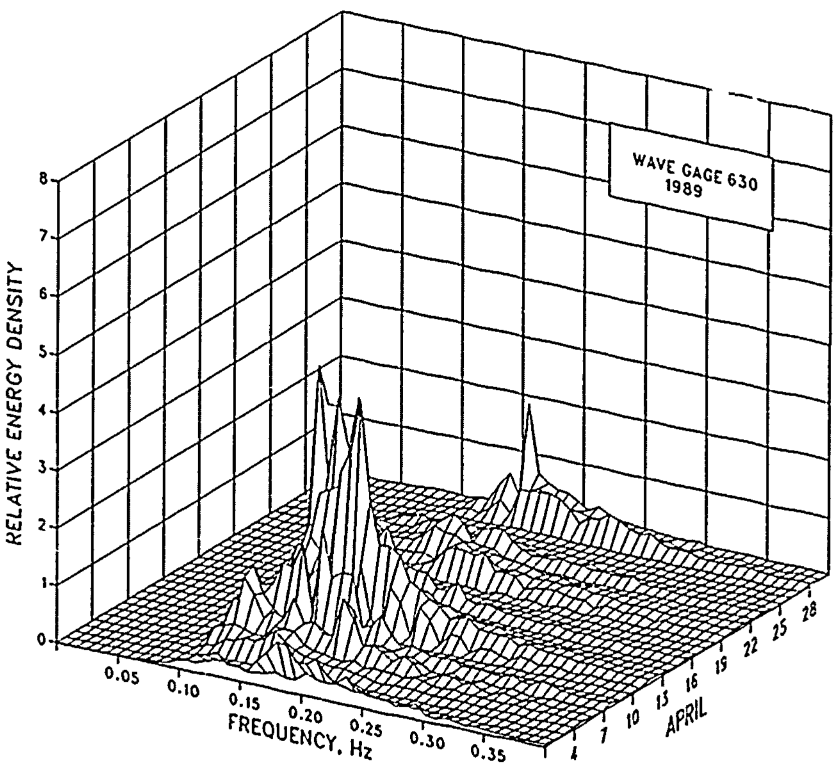
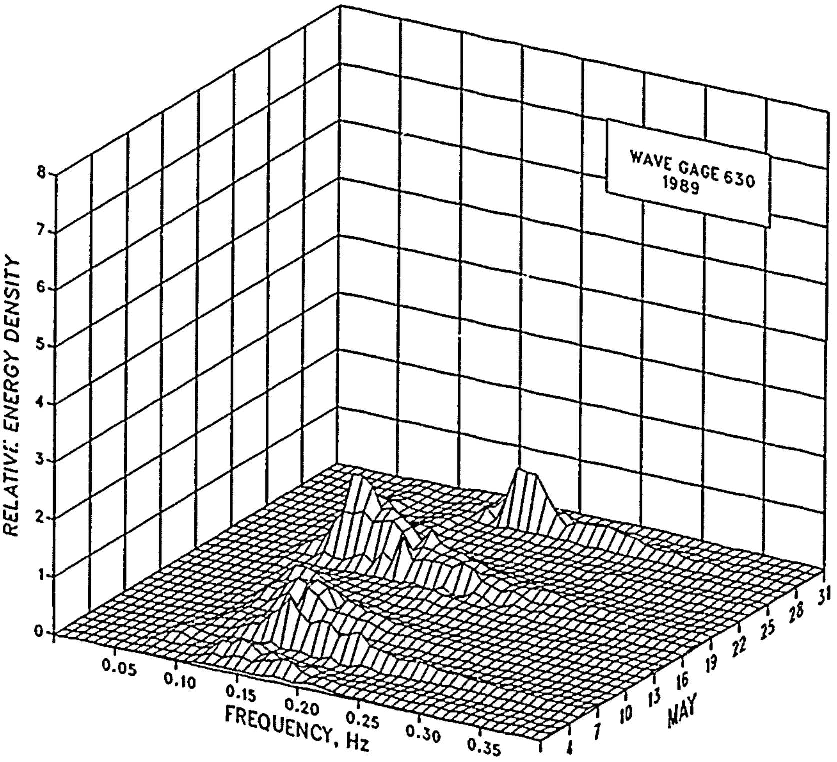


Figure B8. (Sheet 2 of 6)



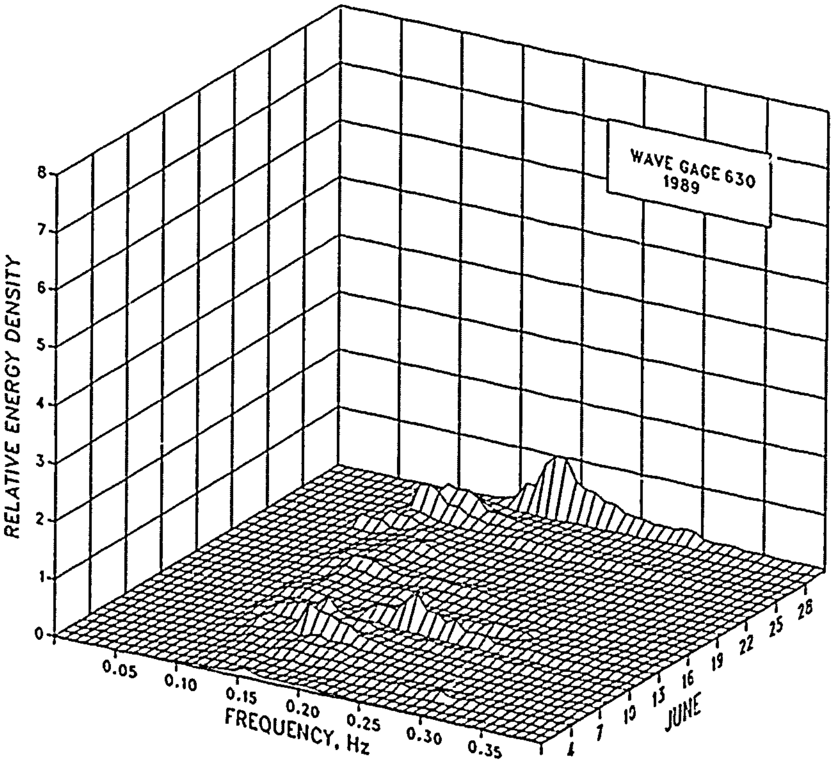
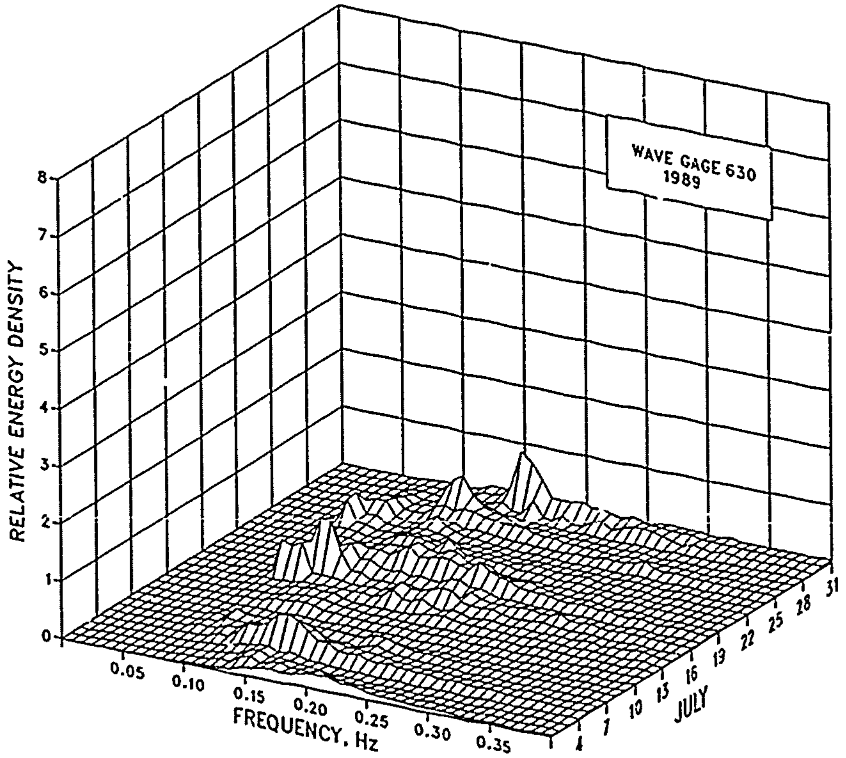


Figure B8. (Sheet 3 of 6)



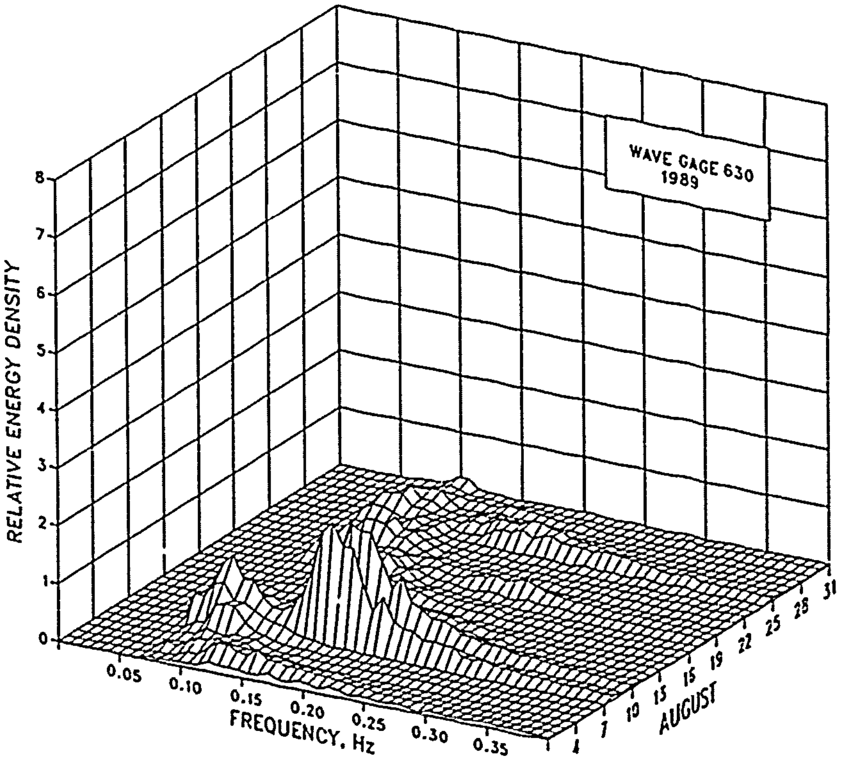
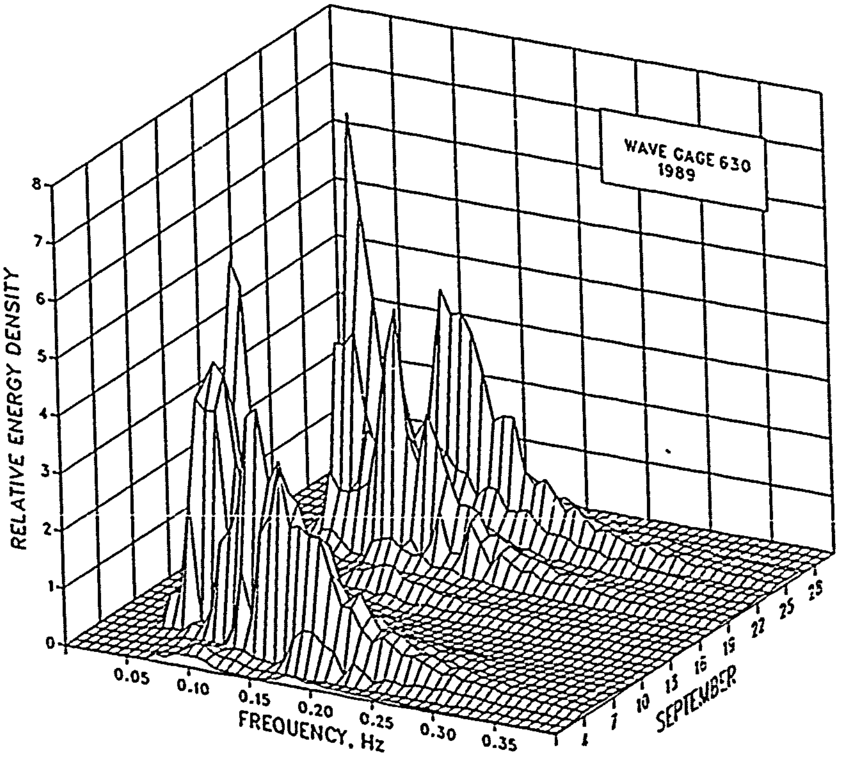


Figure B8. (Sheet 4 of 6)



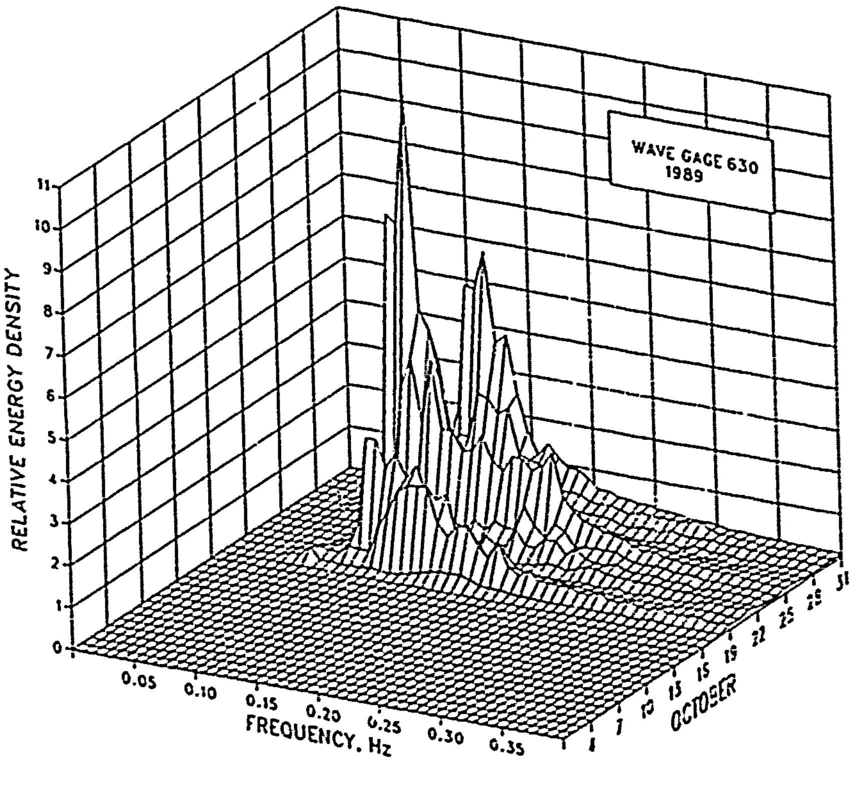
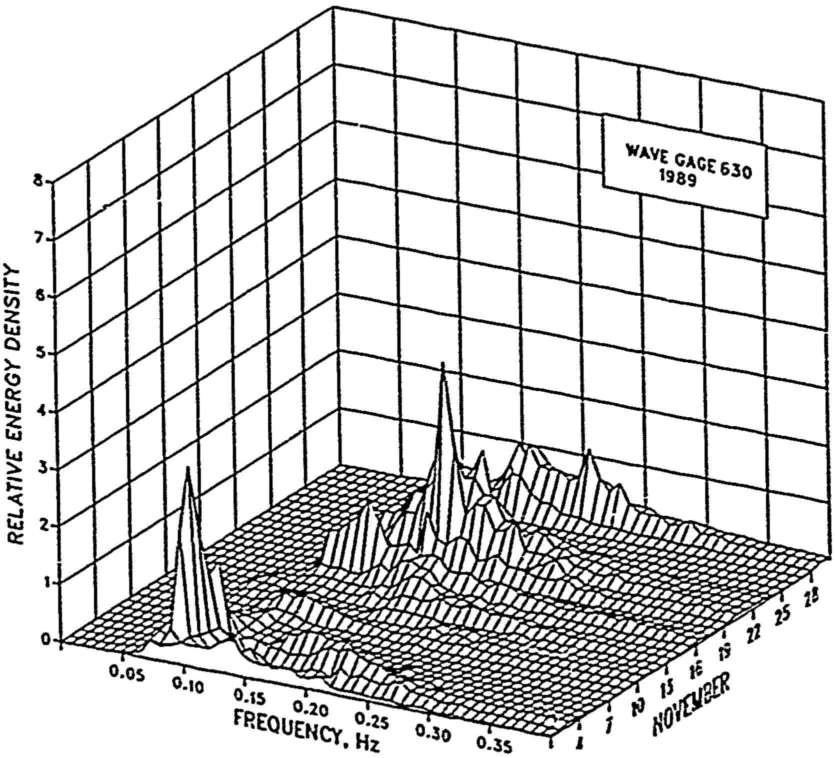


Figure B8. (Sheet 5 of 6)



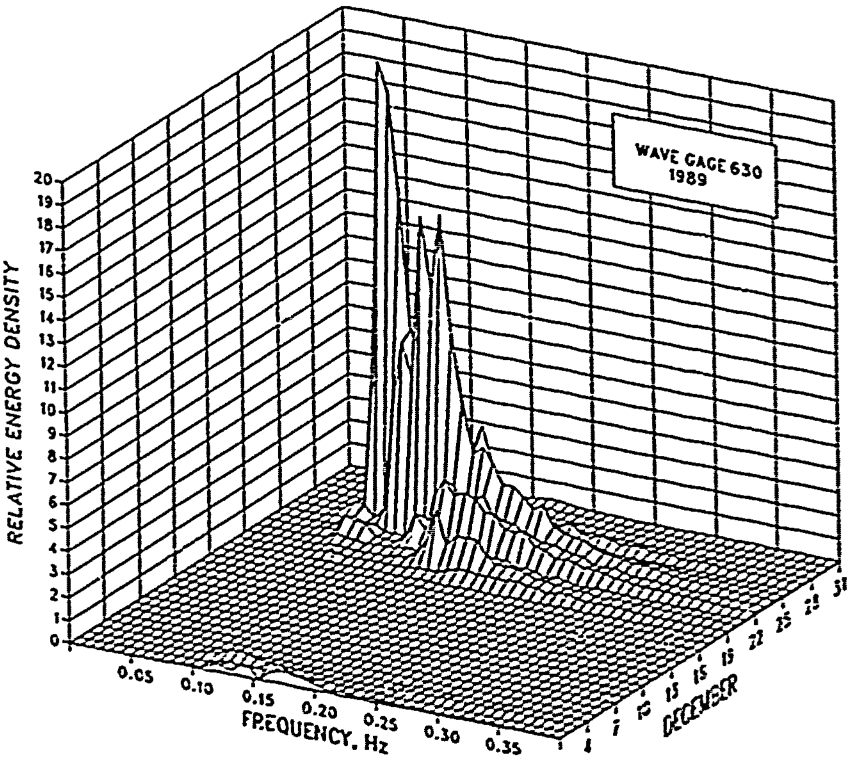


Figure B8. (Sheet 6 of 6)

Table B7

Wave Statistics for Gage 630

	1989							1980-1989						
	Height				Period			Height				Period		
Month	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.
Jan	1.2	0.6	2.9	23	8.2	2.6	121	1.2	0.7	4.5	1983	8.0	2.8	1071
Feb	1.3	0.9	4.3	24	7.6	2.3	105	1.2	0.7	5.1	1987	8.4	2.6	1010
Mar	1.5	1.0	4.2	7	8.2	2.1	123	1.2	0.7	4.7	1983	8.6	2.6	1121
Apr	1.0	0.5	2.3	15	7.7	2.0	117	1.1	0.6	5.2	1988	8.6	2.7	1092
May	0.8	0.3	1.8	28	8.4	3.1	122	0.9	0.5	3.3	1986	8.1	2.4	1105
Jun	0.6	0.2	1.1	29	7.6	2.0	118	0.7	0.4	2.4	1988	7.7	2.2	1045
Jul	0.8	0.3	1.4	29	8.5	2.9	109	0.7	0.3	2.1	1985	8.1	2.5	1057
Aug	0.9	0.4	2.1	8	8.4	2.2	112	0.8	0.5	3.6	1981	8.0	2.4	1061
Sep	1.5	0.7	3.0	24	9.6	3.2	111	1.1	0.6	6.1	1985	8.6	2.7	1071
Oct	1.5	0.7	3.1	26	7.7	2.9	83	1.2	0.7	4.3	1982	8.7	2.8	1122
Nov	1.0	0.4	1.9	21	8.0	3.0	97	1.1	0.6	4.1	1981	7.9	2.8	958
Dec	1.5	1.2	5.6	24	8.1	3.3	59	1.2	0.8	5.6	1980	8.3	3.0	946
Annual	1.1	0.7	5.6	Dec	8.2	2.7	1277	1.0	0.6	6.1	Sep 1985	8.3	2.6	12659

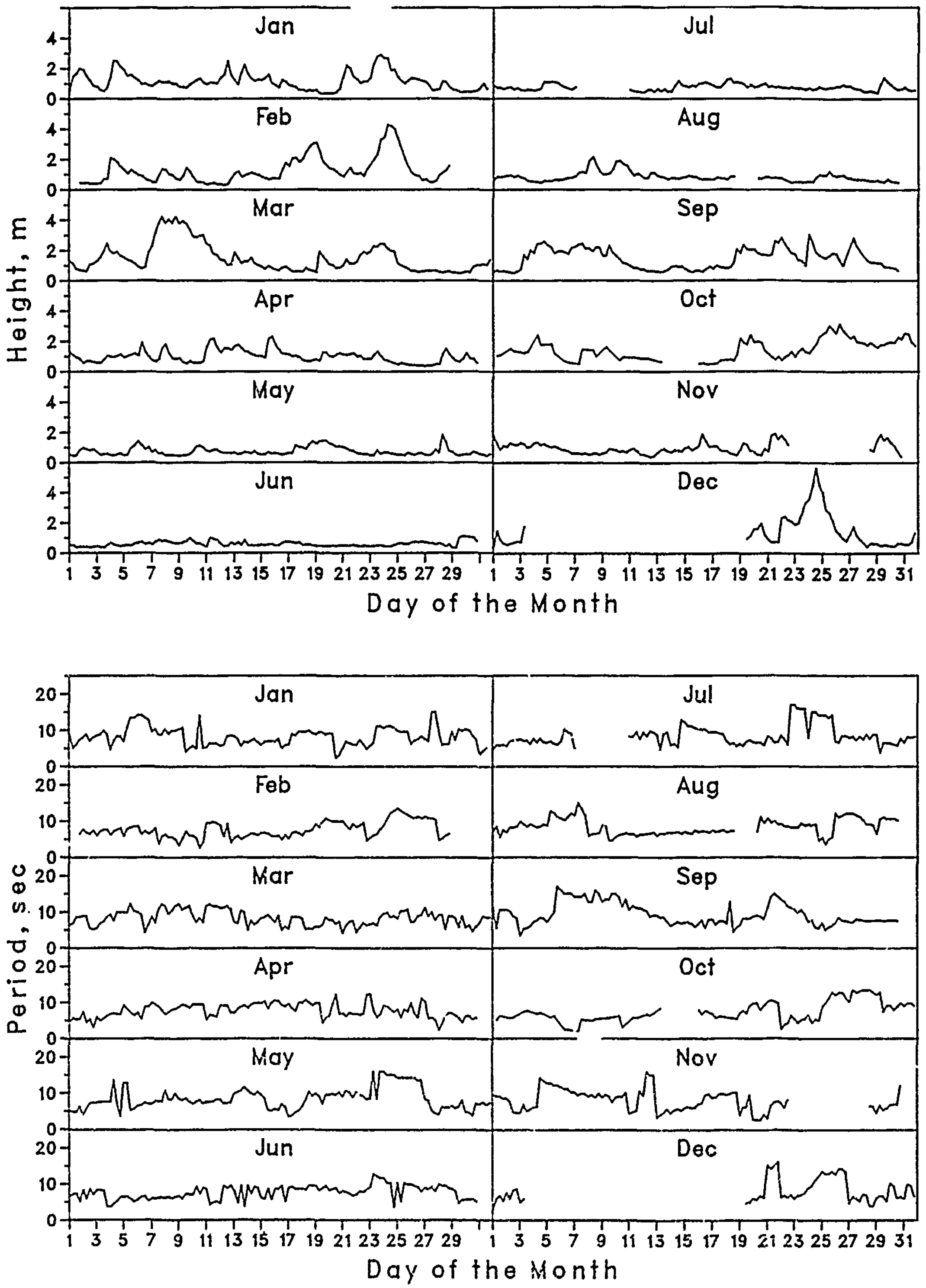


Figure B9. Time-histories of wave height and period for Gage 630